# MEASURING DIELECTRIC PROPERTIES OF SIMULANTS FOR BIOLOGICAL TISSUE

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***Abstract* — We strive to measure the dielectric properties of biological simulants, specifically the value of the dielectric constant for various liquids, and examine the dependency of the dielectric constant on frequency in the range 10 MHz to 100 MHz. This value is determined by using an "open-coax" technique, in which an air-filled, open-ended coaxial line is immersed in the material of which the dielectric constant is desired. By using the known depth of the liquid partially filling the coaxial line and the dimensions of the inner and outer conductors, the dielectric constant can be determined. The calculations involve modeling the impedance of a liquid-filled coax line. Reliable values of dielectric constants of biological simulant materials are important to determine, in order to support theoretical analysis and complex numerical modeling of the energy absorbed from wireless devices that are placed close to, or worn on the human body.**

***Index Terms*— Biological materials, Dielectric constant, Dielectric measurements, Impedance measurement**

## I. INTRODUCTION

A dielectric material is one which is a poor conductor of electricity but a very efficient supporter of electrostatic fields. A common example of a dielectric is the electrically insulating material between the metallic plates of a capacitor. Every dielectric material has a dielectric constant, which describes the extent to which the material concentrates electrostatic lines of flux. One of the most important properties of a dielectric material is how the value of the material's dielectric constant varies with the frequency of the applied electromagnetic field.

Reliable values of dielectric constants of biological simulant materials are important to determine, in order to support theoretical analysis and complex numerical modeling of how the human body absorbs the energy absorbed from wireless devices that are placed close to, or worn on it. Cell phones are a prime example of this, as well as in medicine, where the number of wireless devices that can be implanted directly into the human body is continuing to increase, in order to monitor conditions like blood pressure constantly, while still being unobtrusive to the patient [1].

Devices even just held next to the body, radiate electromagnetic energy and the electromagnetic waves hit the body and partly penetrate it. As a result, the human tissue absorbs a slight bit of the penetrated electromagnetic energy. The measurement technique in this research will help in further determining the dielectric constants of biological simulants and can later be applied to modeling how the human body absorbs this radiated energy.

## II. THEORY

The system we are using to examine the properties of a dielectric material is treated as a cylindrical capacitor. A cylindrical capacitor consists of an inner cylindrical conductor of radius *R1*, surrounded by an outer coaxial cylindrical shell of inner radius *R2*. The length of both of these cylinders is *l*, which is chosen to be much larger than the separation between the two shells (*R2 - R1*) so that edge effects can be neglected.

The basic theory we are using throughout this experiment begins with the permittivity of a cylindrical conductor. In general, for a coaxial cylindrical capacitor, the permittivity ε is written as

$$\varepsilon = \varepsilon(\omega) = \varepsilon_o \varepsilon_r , \qquad (1)$$

where $\varepsilon_o$ is the electric permittivity of free space 8.854 x $10^{-12}$ $F \cdot m^{-1}$ and $\varepsilon_r$ is the relative permittivity, otherwise known as the dielectric constant, which is a complex number that can be written as ε1 - j ε2. The real part of $\varepsilon_r$ should be much larger than the imaginary part, which is essentially insignificant at the low frequency level.

For cylindrical geometry like a coaxial cable, capacitance is usually stated as a capacitance per unit length. The capacitance of a coaxial cylindrical conductor per unit length is

$$\frac{C}{l} = \frac{2\pi\varepsilon_o\varepsilon_r}{\ln\left(\frac{R2}{R1}\right)} . \qquad (2)$$

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Since we are looking at the capacitance per unit length, this eliminates the length $l$ of the capacitors from the above equation. Equation (2) is the capacitance of the liquid filled line. To find the dielectric constant for the dielectric under test (DUT), we must find the capacitance of just the liquid $C_{liq}$, as opposed to the capacitance of the entire system with the liquid inside. The capacitance of the liquid can be written as

$$C_{liq} = \frac{L}{(Z_{liq})^2}, \tag{3}$$

where $L$ is the inductance of the line and $Z_{liq}$ is the impedance of the dielectric material. The inductance $L$ of the line is known, since it only depends on the geometrical factors of our system, and we can solve for $Z_{liq}$ by using a network analyzer to output the system's impedance. This process is explained in the analysis section in further detail. When $C_{liq}$ is calculated, we can insert this into (2) and solve for $\varepsilon_r$ resulting in

$$\varepsilon_r = \frac{C_{liq} \ln\left(\frac{R2}{R1}\right)}{2\pi\varepsilon_o}, \tag{4}$$

which is a complex number and the desired dielectric constant.

## III. Experiment

The system we are using to take measurements was designed in 2009 by Peter Soliman and is shown in Fig. 1 [2]. In this figure, the system is not assembled, but while taking measurements, the inner brass conductor fits inside the outer aluminum conductor and the system is screwed together. The inner cylindrical conductor has radius $R1$ = 16.87 mm. The outer cylindrical shell has radius $R2$ = 38.79 mm. Both have length $l$ = 435 mm.

Fig 1. Cylindrical capacitor used for measurements. The inner cylindrical conductor is made of brass and has radius $R1$ = 16.87 mm. The outer cylindrical shell is made of aluminum and has radius $R2$ = 38.79 mm. Both have length $l$ = 435 mm.

We begin by assembling the system, as shown in Fig. 2, and screwing it into the designed holder so that the coax will not move during calibration or while taking measurements. We then take our coax system and connect it to one port of an E8364B PNA Network Analyzer. We connect a cable with an adapter to the analyzer which will eventually connect to the coax system as shown in Fig. 2.

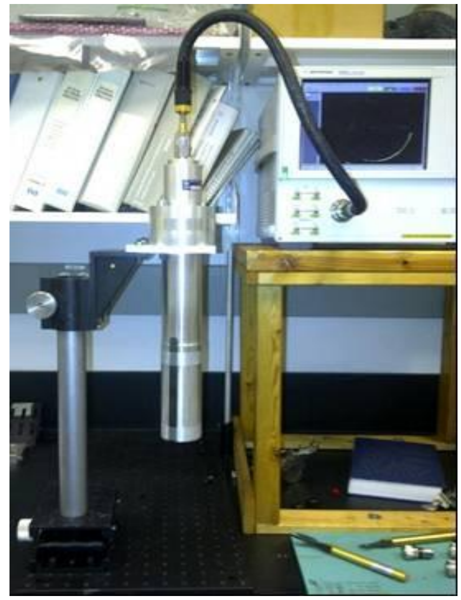

Figure 2. Assembled coax system connected to PNA Network Analyzer.

We connect a cable and adapter to the analyzer which will eventually connect to thee coaxial line. Next, we set the frequencies on the analyzer to range from 10 MHz to 2 GHz. We are only interested in doing final analysis at the low-frequency range of 10 MHz to 100 MHz; however, we will take data over a greater range so that we can extract information about the length of the coaxial line. This is described in greater detail in the analysis section, as well.

Before starting any tests, it is crucial we calibrate the network analyzer as precisely as possible to minimize error. After experimenting with the E-Cal calibration method and the Open-Short-Load (OSL) calibration method, we determined an OSL calibration was the best method. This method consists of calibrating the end of the connectors (in our case the end of an adapter which is on the end of a cable connected to the analyzer) as an open line (infinite resistance), a short line (zero resistance), and with a 50 ohm load on the end of the line. This is an unguided, manual calibration. The Cal-kit we use is an APC 7mm 85050A Cal-kit, but since there is no APC 7 85050A option to choose in the Calibration Wizard, we select the '85050B APC 7 with sliding load' Cal-kit in the "View/Select Cal-kit" option, since the constants are similar to the ones in the 85050A kit we are using.

After the calibration is done as accurately as possible, we connect the coax system to the network analyzer by connecting the newly-calibrated cable and adapter to the coax. The technique we use to take measurements is known as an “open-coax” technique. We use this technique because it has shown to be very promising when taking measurements of the dielectric properties of biomaterials [3]. When using a cylindrical capacitor, this technique provides high-precision measurements because the magnetic and electric fields are confined entirely between the inner and outer conductors. This provides less stray fields and less power loss which allows us to obtain high-precision measurements.

We begin by immersing our air-filled, opened coaxial-line in a transparent container filled with the dielectric material under test (DUT). The beaker is very tall and skinny and has just a slightly larger radius than the coax allowing it to fit inside but with a very small separation between the two, minimizing the meniscus effect of the liquid. There is a ruler with 0.001 m accuracy on the side of our coax system so we are able to see through the container and read the exact depth that the coax system is immersed into the DUT. The inner brass conductor is set up inside the coaxial shell slightly in order to prevent stray field effects, so we must immerse the system in a significant amount of the DUT, preferably an amount greater than 40mm. We record the depth the system is immersed in a first length of liquid and save the Smith Chart data as a .prn file as well as a .cti file. The .prn file is read easily by programs such as Matlab, MathCAD, and Excel. This type of file saves the frequencies being tested and real and imaginary parts of the systems measured impedance with the dielectric material inside. The .cti file is a file which can be recalled on the network analyzer but does not read easily into other programs. It saves the frequency data and the real and imaginary parts of the reflection coefficient, but in a format that is not read easily into other programs.

Next, we take another measurement with the same DUT, but with more of the DUT in the coax system than was in the previous measurement. We do this by adding an additional amount of the liquid to the beaker. We use pipettes to add the additional amount of liquid in order to add the liquid as slowly and accurately as we desire. We again record the depth the system is immersed in this second length of liquid, and save the Smith Chart data as a .prn file and as a .cti file. We will use the data from both of these lengths of the DUT to determine the impedance of the dielectric material, and use that to determine the material’s capacitance, and then finally extract the dielectric constant from the capacitance of the DUT. This is explained in further detail in the analysis section.

## IV. Analysis

All analysis takes place using programs written in Matlab.

### A. *Length Analysis*

It is important to determine the exact length of the line that is filled with *air* while the DUT is inside the system in order to get the most accurate analysis of the material’s dielectric constant. A ruler attached to the side of the coax system allows us to measure the length of the liquid that the line is immersed in to an accuracy of 1 mm, but in order to determine the dielectric constant of the DUT, we must know the exact length of the line that is filled with air during the tests. To get a rough estimate of the amount of the line that is filled with air, we could just simply take the total length of the line, 435 mm, and subtract the length of liquid that the line is immersed in. However, this method is not reliable enough because we are not clear exactly where inside the system the measurement begins. We believe the accuracy of determining the exact lengths of air that the line is filled with during the first and second measurements of liquid is necessary to obtain reliable results for a material’s dielectric constant.

We must determine lengths L1, L2, and L3 shown in Fig.3 for the most accurate calculation of a material’s dielectric constant. The length L1 represents the amount of air that is in our coax system when it is immersed in the first length of the dielectric material, length L3 represents the amount of air that is in the coax system when it is immersed in the second length of liquid, and length L2 is the amount of added liquid, in other words, the difference between L1 and L3. In Figure 3, dotted lines A and B represent the first and second lengths of liquid, respectively.

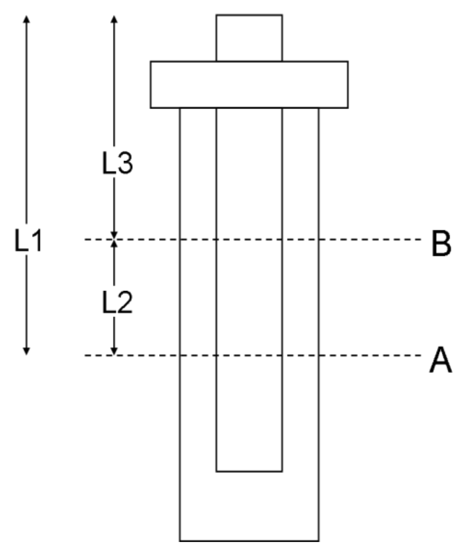


Figure 3. Drawing of the coax system. Determining lengths L1, L2, and L3 to the highest accuracy is imperative to get an accurate calculation for the DUT’s dielectric constant. The dotted lines A and B represent the first and second lengths of liquid, respectively.

Our method of determining these lengths involves examining a graph of the real part of the measured impedance of the system versus the frequency at a range of 10MHz to 2GHz while immersed in the DUT, like shown in Fig. 4. The graph shown in Fig. 4 is a graph of our system filled with 100mm of 0.1 M Saline. We use this large range of frequencies to ensure that we are measuring multiple phases of the system. From the graph, we observe a large spike in the real impedance at each frequency where the network analyzer measures a full phase. We take the difference between two of these peaks, find the corresponding wavelength, and then divide the wavelength by two in order to get the length of the

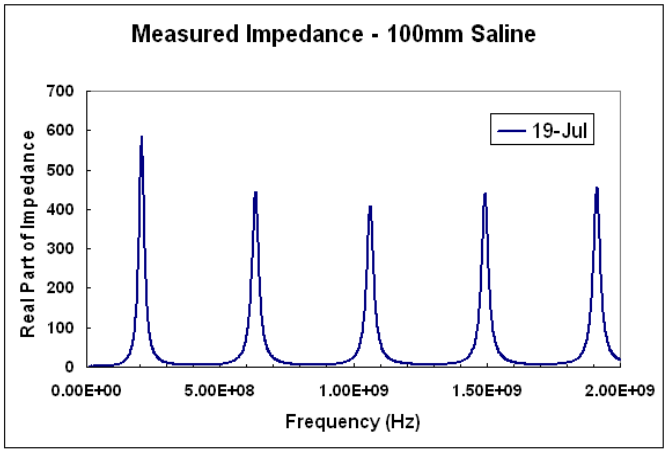


Figure 4. Graph of the systems measured impedance versus frequency for 100mm of .1 M Saline. We use graphs like these to determine the length of air in the coax system while each measurement is taken.

line that is filled with air. We have determined using the later peaks at the higher frequencies is producing more accurate lengths. Because we know the total length of the line and the amount of water the system is immersed in, we have an estimate of about how much air is in the line. The peaks at higher frequencies as seemed to produce lengths closest to the expected value. We believe this might be occurring at higher frequencies because the higher frequencies produce slightly sharper and as a result, more accurate peaks. We do this same length analysis for the first and the second lengths of liquid to find L1 and L3 and then take the difference between these two to find L2.

## *B. Dielectric Constant Analysis*

The analysis of the dielectric constant of the DUT is based primarily on the measured impedance of the coax system. The PNA Network Analyzer outputs the measured impedance of the coax system when we save the data as a .prn file. We call the system's measured impedance with the first length of liquid *Z1*. From theoretical analysis that has been done [8], we know this measured impedance can be expressed as

$$Z1 = Z_0 \frac{(ZL\cos(\beta_{air}L1) + jZ_0\sin(\beta_{air}L1))}{Z_0\cos(\beta_{air}L1) + jZL\sin(\beta_{air}L1)} \quad , \qquad (5)$$

where $Z_0$ is the characteristic impedance of the line, *ZL* is the test impedance at the end of the line with the first length of liquid, $\beta_{air}$ is the propagation constant in the line while it is air-filled, *L1* is the length of the line filled with air while it is immersed in the first length of the DUT, and *j* is the complex unit equal to $\sqrt{-1}$. Because we measure *Z1* from the network analyzer, *Z1* is known for every measured frequency *f*, along with $\beta_{air}$ as well as *L1*, which we determined in the previous length analysis. This leaves *ZL* the only unknown in (5) and we can solve (5) for *ZL* and result with an equation we can use to calculate *ZL* every measured frequency that is written as

$$ZL = \frac{(Z_0 Z1\cos(\beta_{air}L1) - jZ_0^{\ 2}\sin(\beta_{air}L1))}{Z_0\cos(\beta_{air}L1) - jZ1\sin(\beta_{air}L1)} . \qquad (6)$$

Once we solve for each value of *ZL* at every corresponding frequency, we need to find the test impedance at the end of the line with the second length of liquid, *Z2*. Similarly, the network analyzer outputs the measured impedance for the second length of liquid, which we refer to as *Z3*. The expression for Z3 is very similar to (5) and can be written as

$$Z3 = Z_0 \frac{(Z2\cos(\beta_{air}L3) + jZ_0\sin(\beta_{air}L3))}{Z_0\cos(\beta_{air}L3) + jZ2\sin(\beta_{air}L3)} , \qquad (7)$$

where the only unknown is now *Z2*. Since *Z3* is measured, it is known as well as the rest of the variables, and we can solve (7) for *Z2* and result in

$$Z2 = \frac{jZ_0^{\ 2}\sin(\beta_{air}L3) - jZ3Z_0\cos(\beta_{air}L3)}{jZ3\sin(\beta_{air}L3) - Z_0\cos(\beta_{air}L3)} , \qquad (8)$$

where *L3* is the length of the line that is filled with air while the second length of the DUT is in the coax. Again, from previous analysis [8], we also know that

$$Z2 = \frac{Z_{liq}(ZL\cos(\beta_i L2) + jZ_{liq}\sin(\beta_i L2)}{Z_{liq}\cos(\beta_i L2) + jZL\cos(\beta_i L2)} , \qquad (9)$$

where $Z_{liq}$ is the impedance of the liquid in the line, $\beta$ is the propagation constant in the line with the DUT at every corresponding test frequency, and *L2* is the difference between *L1* and *L3*. We also know the impedance of the dielectric material in the line can be written as

$$Z_{liq} = \sqrt{\frac{L}{C_{liq}}} , \qquad (10)$$

where *L* is the inductance of the line and $C_{liq}$ is the measured capacitance of the liquid in the line per unit length. We also know from theory that capacitance can be written as we wrote previously in (2), and (10) can be solved for $C_{liq}$ to get (3).

We can combine equations (5)-(11), to result in the expression

$$Z_{liq}\left(\frac{ZL + j\tan\left(\frac{X_i L2}{Z_{liq}}\right)}{Z_{liq} + j\tan\left(\frac{X_i L2}{Z_{liq}}\right)}\right) = \frac{Z_0 Z3 - jZ_0^{\ 2}\tan(\beta_{air}L3)}{Z_0 - jZ3\tan(\beta_{air}L3)} , \quad (12)$$

where $X_i$ is a constant characteristic to each frequency and is written as $X_i = (2 \cdot \pi f \cdot Z_0)/c_0$, where $c_0$ is the speed of light. Since every variable in (12) is known except $Z_{liq}$, we use the "solve( )" function in Matlab to extract $Z_{liq}$ from (12) and are then able to calculate $Z_{liq}$ for every tested frequency. Once we have $Z_{liq}$, we can use (3) to calculate $C_{liq}$ and then use these values to plug into (4) and solve for $\varepsilon_r$, the dielectric constant. The dielectric constant will be a complex number $\varepsilon_1 - j\varepsilon_2$ with a real part $\varepsilon_1$ and imaginary part $\varepsilon_2$.

## V. Results and Discussion

### A. Results

We investigate our current analysis method by comparing our results to previously measured data for saline solutions fitted to a function and an analysis program in MathCAD and based on earlier work by Stogryn [4, 5]. These results are shown in Fig. 5 and are graphs that we are striving to achieve with our system. It is clear from Fig. 5 that in the 10 MHz to 100 MHz range, the real part $\varepsilon_1$ of the dielectric constant of 0.1 M Saline ideally should not vary more than +/- 0.001 from 76.344, while the imaginary part $\varepsilon_2$ of the dielectric constant of 0.1 M Saline varies over a much larger range, spanning anywhere from $1.82 \times 10^2$ to $1.82 \times 10^3$.

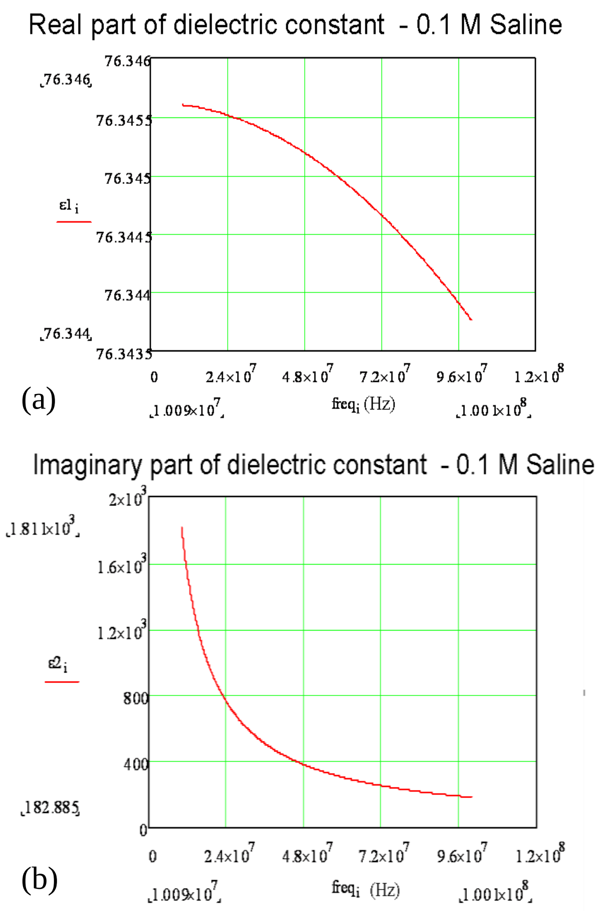


Figure 5. Graphs (a) and (b) are based on previous work for 0.1 M Saline and are the results we desire to find using our measurement and analysis techniques [4, 5]. Graph (a) shows the real part $\varepsilon_1$ of the dielectric constant versus measured frequency, while graph (b) shows the imaginary part $\varepsilon_2$ of the dielectric constant versus measured frequency.

Currently, our analysis is producing graphs like are shown in Fig. 6. Comparing our graphs to the ideal results in Fig. 5, it is clear that our current analysis technique is not currently providing sufficient accuracy. We notice the imaginary part of the data looks somewhat accurate, with most of the data remaining in the range of $1.82 \times 10^2$ to $1.82 \times 10^3$ and following a very similar behavior to that seen in Fig.5. However, the real part of our 0.1 M Saline data varies largely from the ideal values shown in Fig. 5 for what we expect in the low-frequency range. Not only does our data not match the expected value of 76.344 +/- 0.001, it spans over a significant range with the majority of our data somewhere in between 0 and 800. This is not at all what we expect which leads us to believe there is a discrepancy in our analysis. It is also important to note Fig 6. shows the absolute value of the real

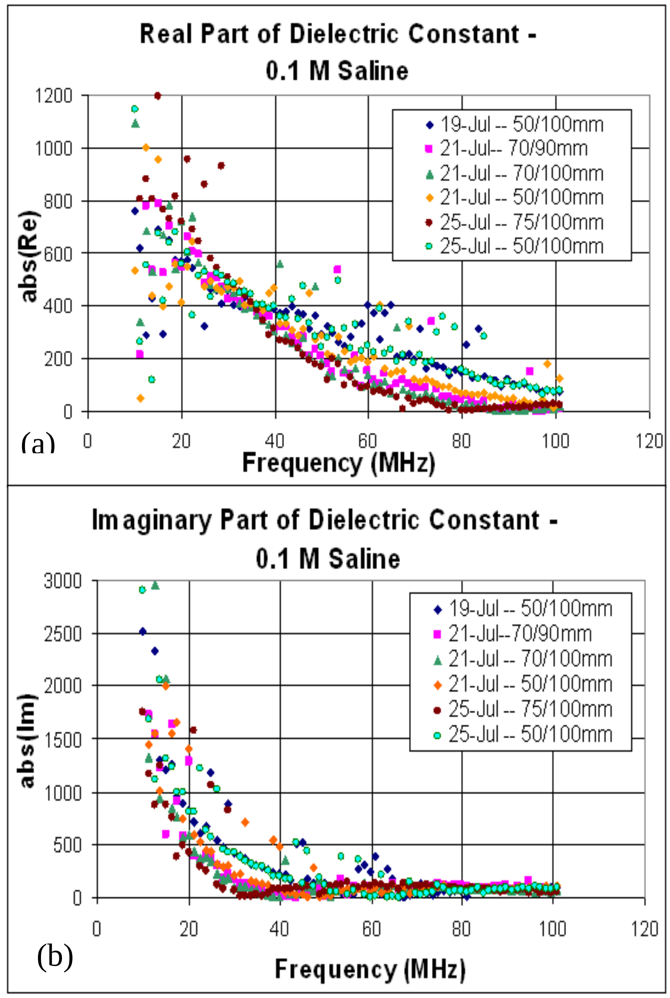


Figure 6. Results from our current analysis technique of determining a material's dielectric constant. Graphs (a) and (b) show the absolute value of real and imaginary parts of the dielectric constant versus frequency,

and imaginary parts of the dielectric constant. Most of all the measured values were negative and this is not at all what we expect. We graph the absolute value because perhaps the sign difference is a discrepancy in the analysis.

While the data for our 0.1 M Saline strays significantly from expected values, we believe our analysis technique is not entirely inconclusive. We also performed tests using tap water and the resulting data is shown in Fig. 7.

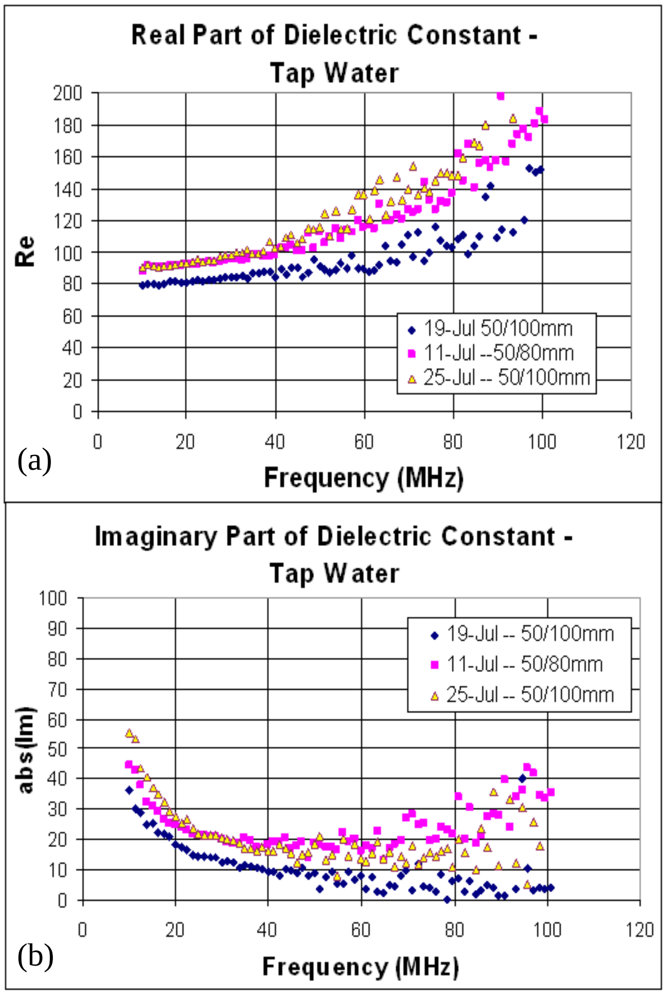


Figure 7. Graphs (a) and (b) show the calculated real part and absolute value of the imaginary part of the dielectric constant of tap water versus frequency using our current analysis technique. This graph shows our analysis is promising because we know the expected value of the real part of the dielectric constant of water is 80.22 at room temperature of about 20° C [7].

When using tap water, the real part of the data, shown in Fig. 7(a), initially appears like we expect up until about 25 MHz, remaining relatively constant at a value of about 80. We believe 25-Jul and 11-Jul data is slightly offset from the 19-Jul data because of a slight offset in calibration, but behavior of these two is exactly the same as the 19-Jul data. We know from previous work that at room temperature, the dielectric constant of water should remain around 80 while in the low-frequency range, and when it reaches about 1 GHz the value of the real part of the dielectric should begin to decline [5, 6]. When our data passes about 25 MHz, the real part of the dielectric constant begins to scatter and increase in value. This behavior is unexpected and shows that there may be some increase of noise in the data when it reaches 25MHz. While Fig. 7(a) shows somewhat promising behavior, the imaginary part of the dielectric constant shown in Fig. 7(b) does not follow expected behavior. Previous measurements and analysis of the dielectric constant of water says that the imaginary part of the dielectric constant should remain very small, very close to but not below zero, until it reaches the high-frequency range [6, 7]. In Fig. 7(b) we are again graphing the absolute value of the data because the majority of the data was below zero. We can see however, that in Fig. 7(b) as the data approaches 100 MHz, it seems to be somewhat approaching zero, more like we expect.

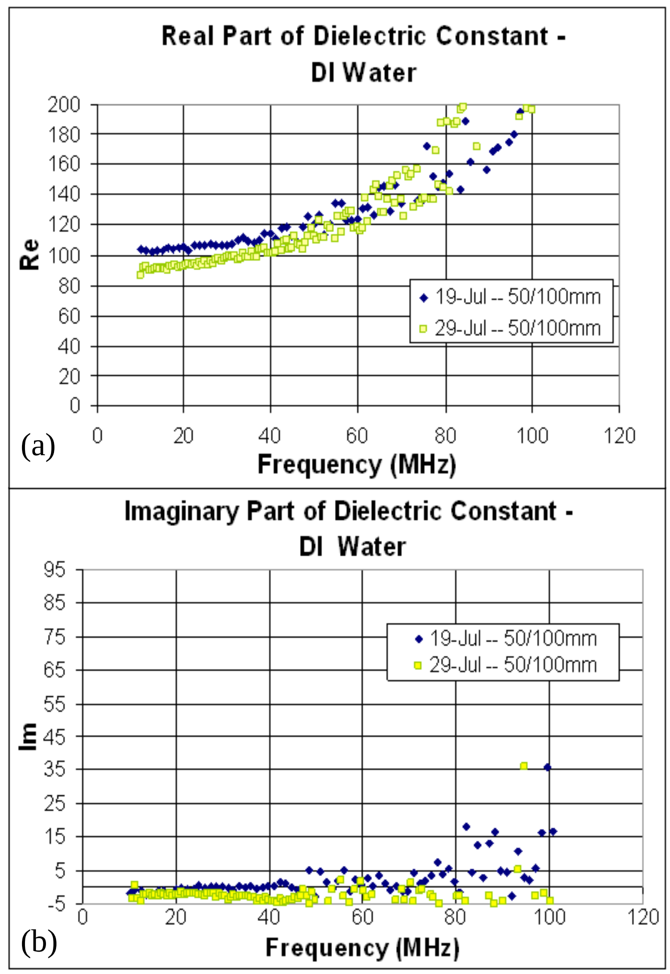


Figure 8. Graphs (a) and (b) show the calculated real part and imaginary part of the dielectric constant of DI water versus frequency using our current analysis technique. Error in the imaginary part of the data is significantly reduced.

Recently, we just began examining the system with deionized (DI) water. We expect DI water to be much purer than the tap water data; however in Fig. 8, it is clear that the real part of the DI water data follows almost the same behavior as the tap water and does not appear to have much reduction of noise or any significant increase in accuracy. The real part of the dielectric constant, shown in Fig. 8(a), is shifted slightly upward from the expected value of 80, perhaps from an imprecise calibration, but the behavior of the data appears almost identical to the real part of the dielectric constant with tap water. Comparing the very little increase in accuracy between tap water and DI water, we can infer that the error in accuracy is not the data measurements, but the analysis. The one large difference between the tap water data the DI water data is the imaginary part of the dielectric constant. We can see in Fig. 8(b) that the imaginary part of the dielectric constant behaves much more like we expect, remaining very close to zero but still becomes significantly scattered as the frequency increases. With this data, we do not need to plot the absolute value of the real or imaginary part of the data

*B. Discussion*

It is important to note the difference in the saline data and the tap and DI water data. The tap and DI water data appears noisier at the end of the frequency range, while the saline data appears most noisy right at the beginning of the frequency range. Also, we do not expect tap water data to appear cleaner and more accurate than the saline data. Tap water has many impurities while the saline solution is made with solely deionized water and sodium chloride (NaCl). This is made clear when we examine the plots of the complex reflection coefficient on the network analyzer. The impurities in the tap water create glitches in the data that are very apparent. However, when examining the plots of the system with saline inside instead of tap water, all the glitches in the data seem to be gone. This behavior is shown in Fig. 9, which shows plots of the complex reflection coefficient of the system with both 100mm of tap water and inside. In Fig. 9(a) with the tap water, we see wavy lines and a random unexplained loop in the middle. In Fig. 9(b) with the saline solution, we see very smooth data as we expect with consistent behavior. It is important to remember the graphs on the network analyzer are of the complex reflection coefficient. When we save the data as a .prn file, the analyzer takes the data for the reflection coefficient and converts it to the measured impedance of the system. Perhaps while the analyzer converts the data into the .prn format, some noise is introduced in the process. This may explain why the noise reduction between the tap water and saline solution is not as drastic as it appears on the network analyzer, however it still does not explain why the end of the tap water data has the most noise and the saline data appears to have the exact opposite behavior.

(a)

(b)

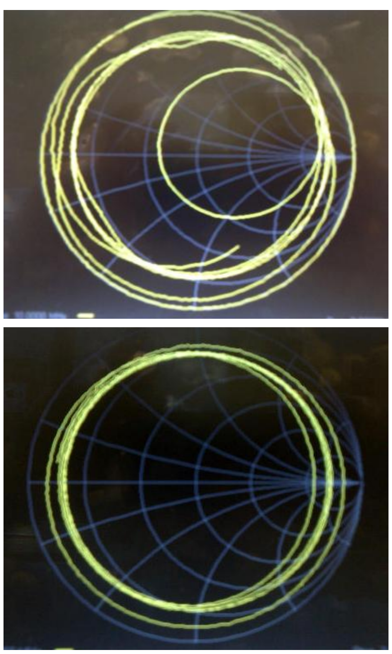

Figure 9. Graphs (a) and (b) show the complex reflection coefficient for 100 mm of tap water and saline inside the coax, respectively. Impurities in the tap water data is made very apparent compared to the graph of 0.1 M Saline.

The calibration method also has the potential to be improved. Since we are currently using the 85050A Cal-kit but this kit is not available in the PNA Network Analyzer's Calibration Wizard, some of the calibration constants may be slightly off which will produce and offset in the system's measurements. This inaccuracy is most noticeable in the open calibration. Both the short and the load calibration look like very precise dots on the Smith Chart, while the open calibration is consistently the most imprecise. This may be because the open calibration constant in the 85050B kit is slightly different than the open calibration piece we are using in the 85050A kit. Experimenting with different Cal-kits or even perhaps different calibration methods could reduce some of this error in the calibration.

We believe this current analysis program is very sensitive to noise in the data as well as very sensitive to the exact length of air in the system during measurements. Especially if more noise is introduced to the data when the analyzer converts from complex reflection coefficient to the impedance, this sensitivity in our analysis program becomes a major complication. We believe the data is not incorrect, but the analysis program contains certain features that are causing insufficient accuracy. The sensitivity to noise must be reduced in this analysis program before we can calculate reliable dielectric constants.

## VI. Conclusion and Future Work

We use an open-ended coaxial line to investigate dielectric properties of simulants for biological tissue. The "open-coax" measurement technique gives values of input impedance that can be analyzed to get the dielectric constant. We desire to determine a reliable value of the dielectric constant for various liquids, and examine the dependency of that constant on frequency in the range 10 MHz to 100 MHz. Reliable values of dielectric constants of biological simulant materials are important to determine, in order to support theoretical analysis and complex numerical modeling of the energy absorbed from wireless devices that are placed close to, or worn on the human body.

Before we can measure the dielectric properties of biological simulants, we must get reliable data for the dielectric properties of liquids whose dielectric properties are already well-known. We use an "open-coax" technique which involves taking the air-filled, open-ended coaxial line and immersing it in the material of which the dielectric constant is desired. This project has been primarily working with water and saline solutions to determine if our current analysis method is outputting reliable dielectric constants. The analysis program we are using to calculate the dielectric constant is currently inconclusive. This analysis technique takes the measured impedance of the liquid-filled coax line and uses the known depth of the liquid partially filling the coaxial line and the dimensions of the inner and outer conductors to determine the dielectric constant. We believe this analysis program is extremely sensitive to noise in the data. It is also very important with this analysis that we measure the amount of air in the coaxial line as precisely as possible while taking measurements to minimize error.

A new analysis program is currently under development that may be less sensitive to noise and the exact measurement of air in the system. When this analysis is done, both methods of analysis can be compared to further develop this project. This coaxial system and measurement technique have the potential to be very effective in determining the dielectric constant of biological simulants with improved calibration techniques and a more accurate analysis program.

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