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 their dependency on frequency in the range 10 MHz to 100MHz. 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.

Theory

$$C = \varepsilon \frac{A}{d} = \frac{2\pi\varepsilon_o\varepsilon_r}{\ln\left(\frac{R2}{R1}\right)}$$

Capacitance

$$L = \frac{\mu_o}{2\pi}\ln\left(\frac{R2}{R1}\right)$$

Inductance

$$Z = \sqrt{\frac{L}{C}}$$

Impedance

We use a network analyzer to measure the systems impedance with the dielectric inside. Using these equations we can work backwards to solve for the dielectric constant of the material.

Experiment

- Cylindrical Capacitor

Figure 1. Coaxial cylindrical capacitor used to take measurements, unassembled.

- "Open-coax" technique
  - Immerse coaxial line in dielectric material
  - Record data for one depth of liquid
  - Add more of the dielectric material
  - Record data with additional depth of liquid

Figure 2. Coax system assembled and connected to network analyzer.

Analysis and Discussion

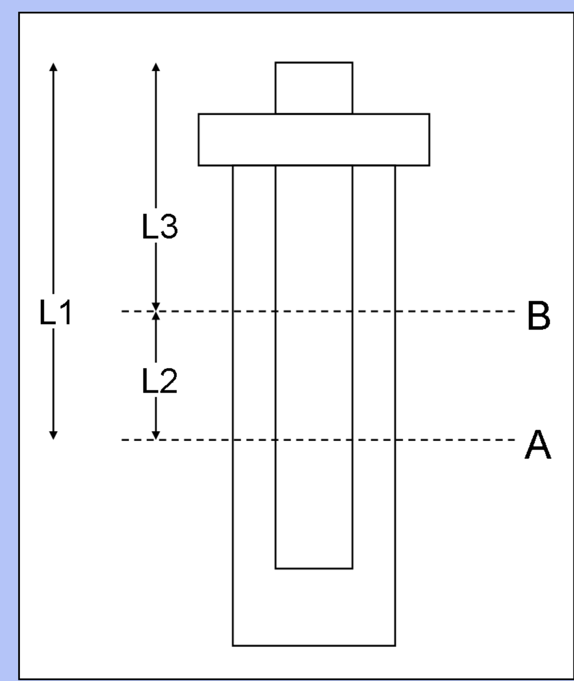

Figure 3. Diagram showing lengths of air in system which must be determined for accurate analysis. Lines A and B represent the first and second lengths of liquid the system is immersed in, respectively.

Length Analysis

- Must determine lengths of line that are filled with air during measurements
- Unaware of **exact** location where the measurement of the network analyzer begins
- Ruler on outside of coax tells us depth of liquid to 0.001 m but unable to see inside system

- Large spikes occur in measured impedance data every time the analyzer completes the measurement of one full phase
- Find the difference in frequencies where two peaks occur, find corresponding wavelength, and divide by 2 to determine length of air in line
- Currently, length is greatest source of error in analysis

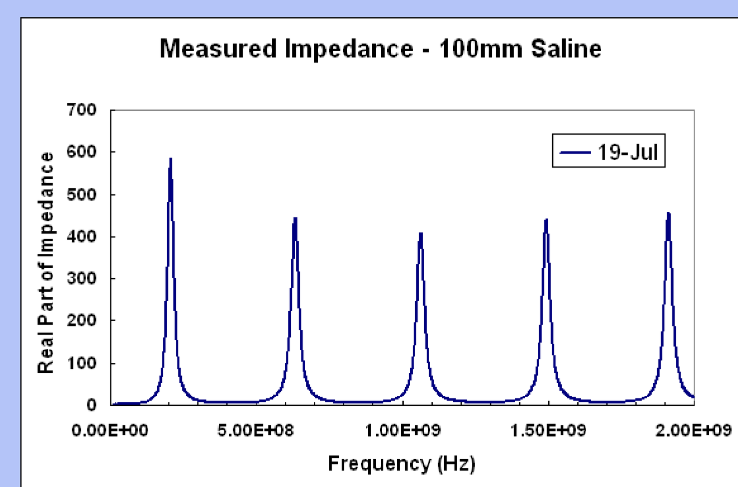

Figure 4. Example of graph showing the peaks that occur at each time the network analyzer measures a full phase. We use the difference between two of these peaks to find the length of air in the line during the measurement.

Dielectric Constant Analysis

- Import measured impedance data into Matlab analysis program
- From theory, calculate the system's input impedance for both lengths of liquid
- Extract from equations impedance of liquid
- Use theory equations to solve for dielectric constant
- Experimental data show similar behavior to what is expected but precise values have considerable scatter

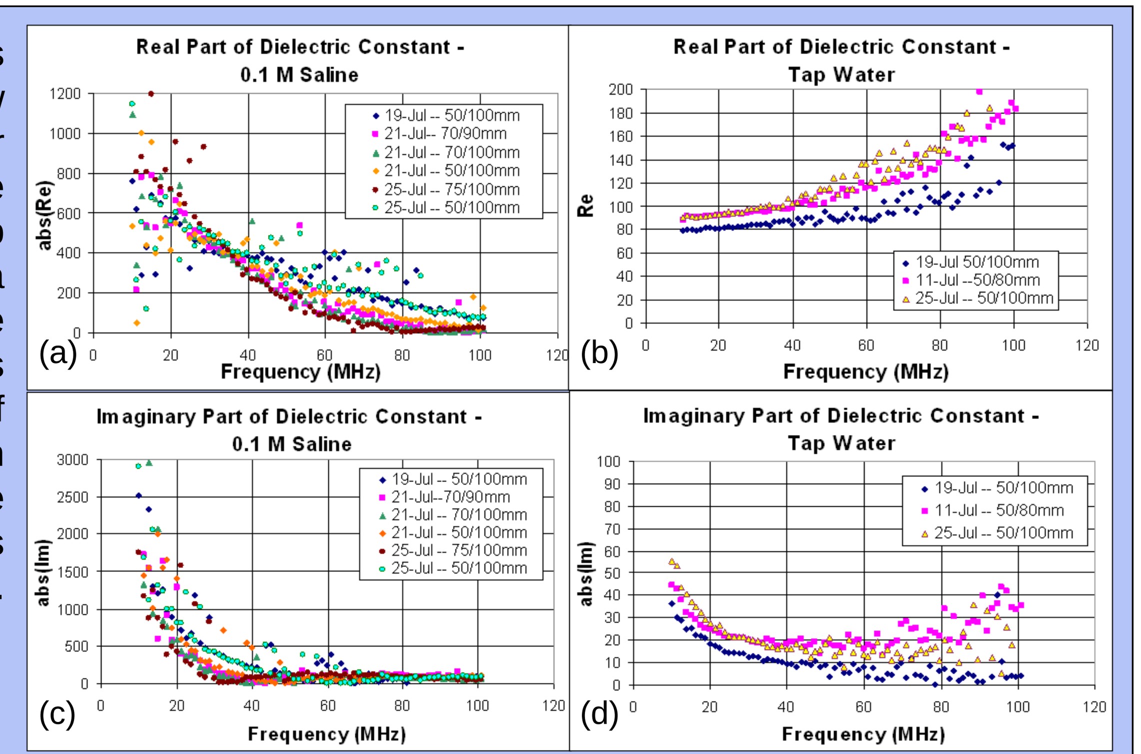

Figure 5. Graphs (a)-(d) show calculated data for 0.1 M Saline solutions and tap water. Saline data appears to be more noisy and less accurate than that of tap water, while on the analyzer the saline data appears much cleaner.

- We do not expect tap water data to appear cleaner than saline solution
- Analysis may be very sensitive to noise in the data and on exact length measurements used

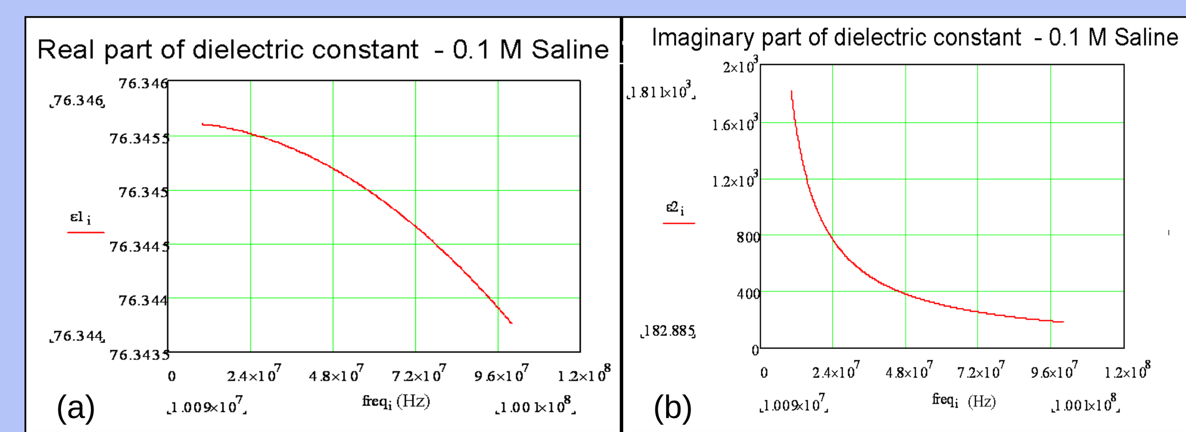

Figure 6. Graphs (a) and (b) are from previously measured data for saline solutions fitted to a function and an analysis program in MathCAD [1], based on earlier work by Stogryn [2].

Conclusion and Future Work

- Measurement technique has potential to be very useful in determining dielectric properties of biological simulants
- Current analysis program is inconclusive; possibly very sensitive to noise
- Length analysis is largest source of error
- Another analysis method, which may not be as sensitive to noise or to the length measurement, is being developed
- Compare the two different methods of analysis
- Develop another way of measuring the length of air in the line

Acknowledgements & References

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[1] C.C Davis, "Dielectric properties of saline solutions", University of Maryland Institute for Systems Research Report Number 2001-11 (2001).

[2] Stogryn A 1971 Equations for calculating the dielectric constant of saline water *IEEE Trans. Microw. Theory Techn.* **19** 733–7