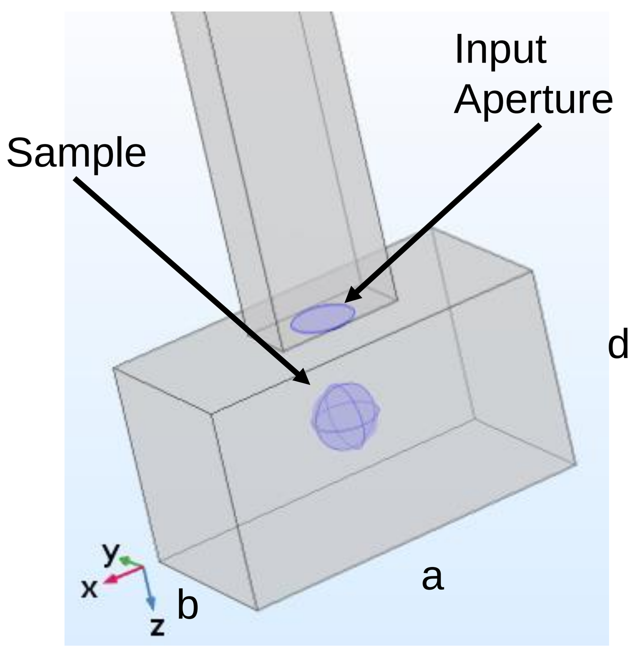
Dielectric Measurement of a High Permittivity Liquid

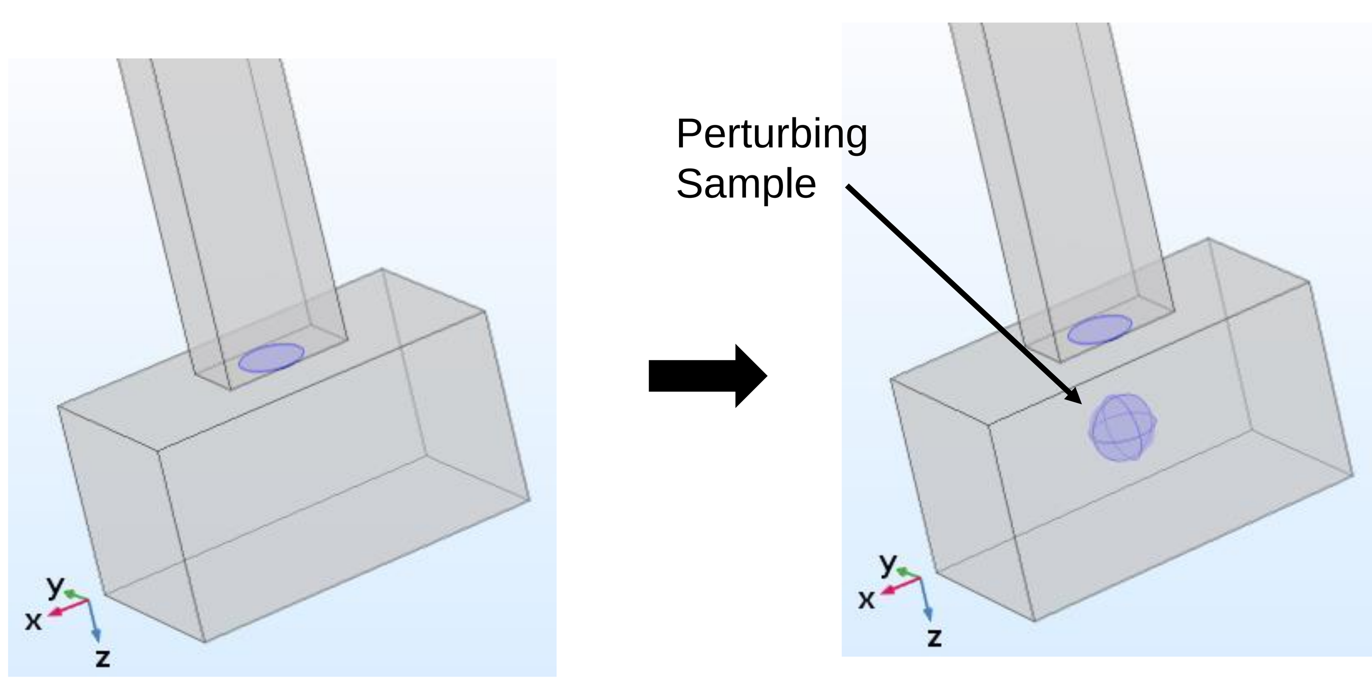
D. Karns[1], Z. Landicini[1] and J. C. Weatherall[1]
1. Battelle Memorial Institute, Atlantic City, NJ, USA

Resonant Cavity Measurement System, 75 GHz to 110 GHz



- High and low loss liquids
- a = 7.11 mm
- b = 3.56 mm
- d = 4.0 mm
- Input aperture radius = 1 mm
- Sample volume as small as 0.2 mL

Figure 1. Illustration of Resonant Waveguide Measurement System



$$\frac{f_c - f_s}{f_s} = (\varepsilon' - 1)\frac{2V_s}{V_c}$$

Figure 2. Illustration of Perturbation Theory with a Resonant Cavity

Resonant Frequency Measurement of DI Water

Generally, the resonant frequency shifts to lower frequencies when an air-filled cavity is perturbed with a dielectric sample, as shown in Figure 2. However, for DI water the resonant frequency sometimes shifted to higher frequencies in experimental data, as shown in Figure 3

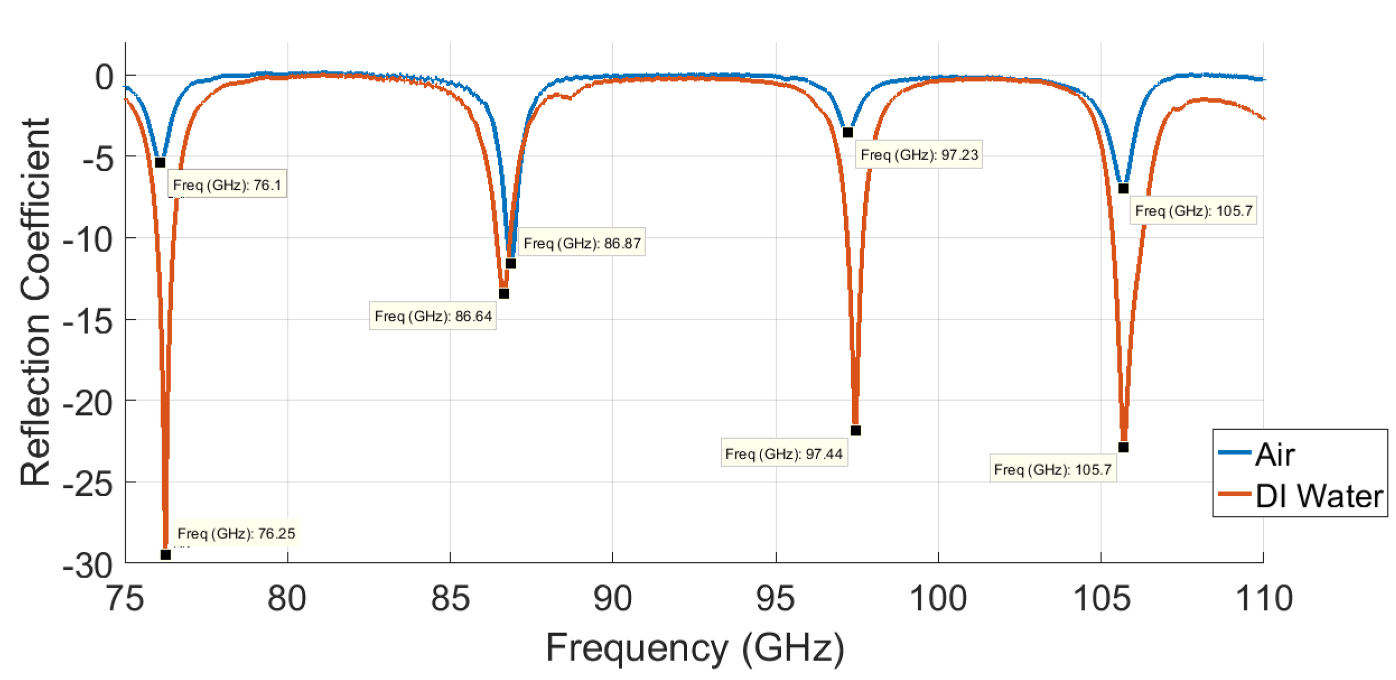


Figure 3. DI Water, Perturbed Resonant Frequency Shift to Higher Frequencies

Initial Simulation of DI Water

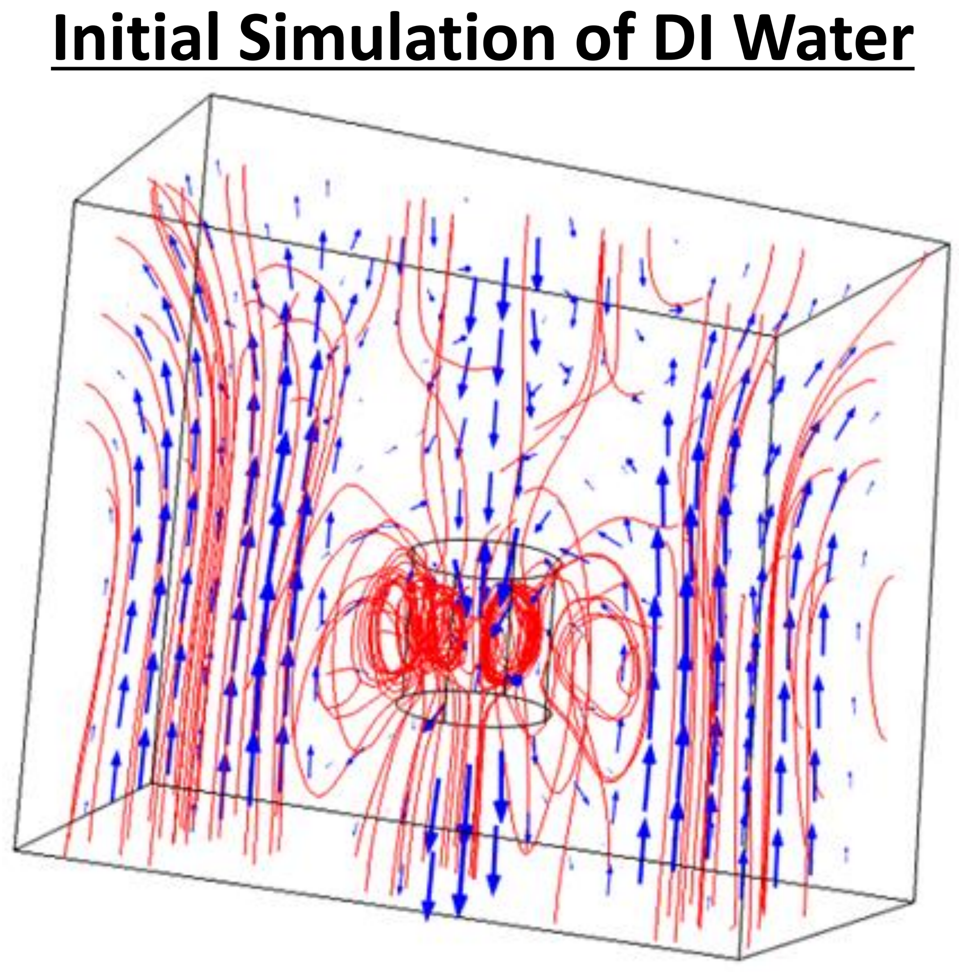


Figure 4. Simulation of DI Water at 26.2 GHz. Arrows are E-field, lines are E-field streamlines (Note: Different Mode Structure in Sample).

Simulating the Resonant Cavity Measurement System with Spherical Samples for a Range of Heights (Radii)

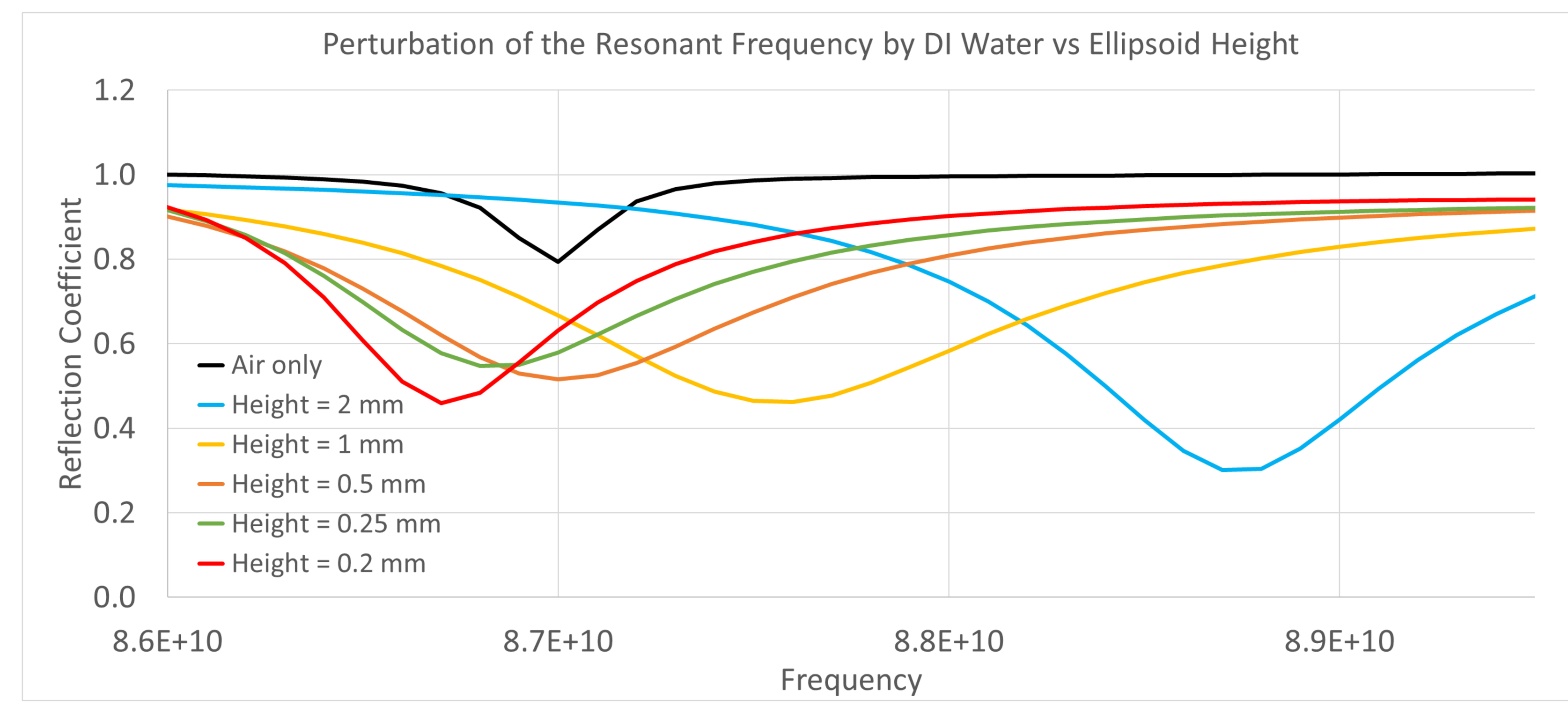


Figure 5. Resonant Frequency (@87 GHz) Shift versus Spherical Sample Height

The height (radius) of the spherical sample determines whether the resonant frequency shifts to higher or lower frequency. Ellipsoidal heights greater than 0.5 mm cause the resonance to shift higher in frequency.

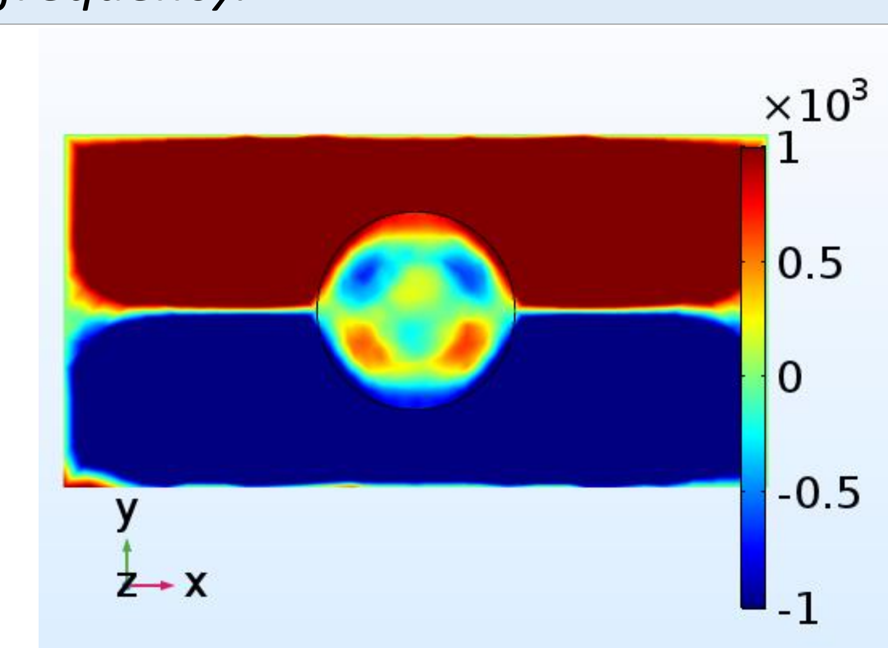


Figure 6. Simulation of the Z-direction Component of the E-field for a sphere with radius of 1 mm (Note: Different Mode Structure in Sample)

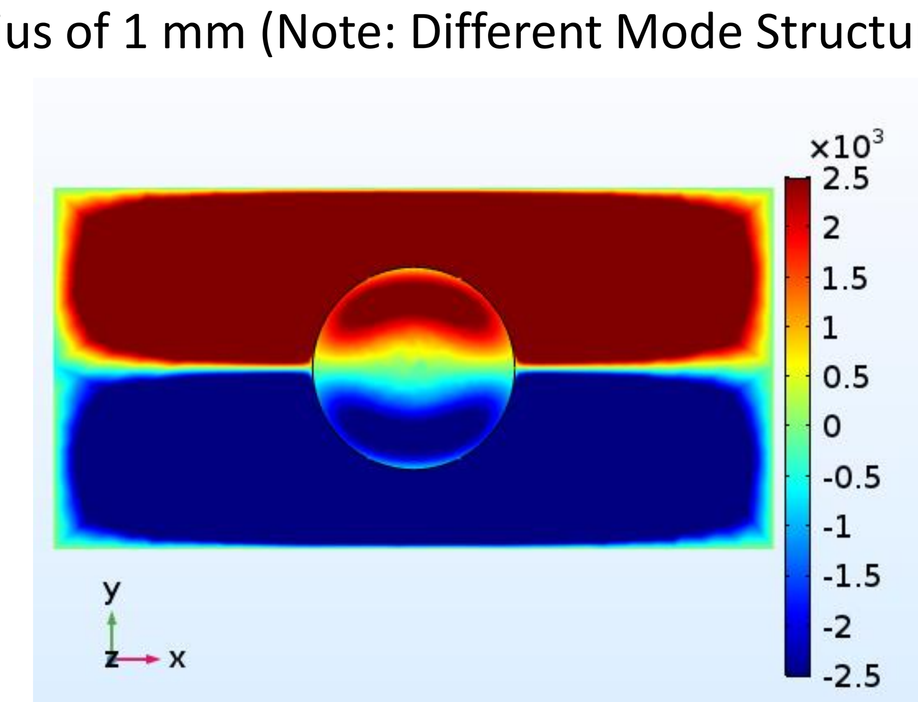


Figure 7. Simulation of the Z-direction Component of the E-field for a sphere with radius of 0.2 mm (Note: Mode Structure Continues in Sample)

Radii greater than 0.5 mm show a different E-field mode structure in the sample than the E-field mode structure in the cavity

Conclusions from Simulations

In DI water samples with the height of the sphere less than 0.5 mm, the resonant mode structure of the E-field is maintained in the sample. This upholds a fundamental requirement for perturbation theory and yields a shift in resonance to lower frequencies.
In DI water samples with a sphere radius greater than 0.5 mm, the E-field resonant mode structure is not maintained. This results in an effectively smaller cavity size and causes the resonance to shift to higher frequencies.

References

[1] D. Karns, Z. Landicini, J.C. Weatherall, P.R. Smith, J. Barber and B.T. Smith, "Millimeter Wave Measurements of the Complex Permittivity for DI Water", Battelle Memorial Institute, Technical Note (2019)
[2] J.C. Weatherall, J. Barber, J. Greca and B.T. Smith, "WR51-Cavity for Precision Dielectric Measurement 10 to 40 GHz", Battelle Memorial Institute, Technical Note (2014)

Excerpt from the Proceedings of the 2019 COMSOL Conference in Boston