Error Reduction in the Measurement of the Dielectric Constant of Seawater at 1.413 GHz

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Outline

- Purpose
- Experiment Setup
- Algorithm
- Calibration Using Methanol
- Seawater Measurements
- Results
Purpose

- Develop an **accurate** model for the dependence of the dielectric constant of seawater on **temperature** and **salinity**.

- The dielectric measurements should have an **accuracy of 0.2%** to meet the Aquarius goal of measuring salinity to an **accuracy of 0.2**.
Cavity Technique

Network Analyzer (NA) provides 1601 points of power versus frequency. The NA also calculate the cavity resonant frequency and the Q value.
The Algorithm

- Use perturbation theory.
- Valid when sample volume is small.
- The dielectric constant, $\varepsilon = \varepsilon' + i\varepsilon''$ of the sample is:

$$\varepsilon' - 1 = 2C \frac{\Delta f}{f}, \quad \varepsilon'' = C\Delta \left( \frac{1}{Q} \right)$$

$$\Delta f = f - f_0, \quad \Delta \left( \frac{1}{Q} \right) = \frac{1}{Q} - \frac{1}{Q_0} = \frac{BW}{f} - \frac{BW_0}{f_0}$$

C-Calibration Coefficient
Experimental Setup

Circulator

$N_2$

Network Analyzer

JPL Cal/Val workshop, Nov 2011
Cavity Description

- Naval brass cavity was placed in a coolant for temperature control.

- Quartz capillary tube of 0.1 mm inner diameter in the cavity is used to channel sample solution through cavity.

- Use nitrogen to push the sample solution through the tube.
Calculation of C Constant

- Based on the algorithm, use sample with known dielectric constant value as a reference.

- Obtain C value by:

\[ \varepsilon' - 1 = 2C_1 \frac{\Delta f}{f}, \quad \text{or} \quad \varepsilon'' = C_2 \Delta\left(\frac{1}{Q}\right) \]

- Gregory & Clarke’s methanol results at 20 C are used.
Calibration Liquid --- Methanol


- Three independent measurement techniques were used by Gregory and Clark.

- Used Gregory and Clark’s dielectric constant of methanol measured at 1.2 and 1.5 GHz (20° C).

- Polynomial interpolation method is applied to obtain $\varepsilon'$ and $\varepsilon''$ at 1.413 GHz

- Measurement % error: $\varepsilon' \approx 0.1\%$, $\varepsilon'' \approx 0.1\%$
Changes in Methanol Calibration Method

- Old methanol bottle without rubber cover absorbed water from the air and changed its composition.

- Now new methanol with rubber cover is used to prevent water absorption.

- Observed 2% change in calibration constant between old and new methanol.
Methanol Calibration Results

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<tr>
<td>ERROR(%)</td>
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<td>0.531</td>
<td>-</td>
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</table>

The difference between the results of these two periods is:

\[
\Delta C_1 = 0.258\%, \Delta C_2 = 0.071\%,
\]

We chose \( C_1 \) as our Calibration Constant:

\[
C = \langle C_1 \rangle = 694,651
\]
Procedure for Seawater measurements

- Measure \((f_o, Q_o)\) for empty tube.
- Put seawater into the reservoir and wait for about 15 minutes until the temperature of seawater reaches the cavity temperature.
- Use nitrogen to push seawater into capillary tube.
- Measure \((f, Q)\) for seawater.
- Push seawater out and use distilled water to clean the tube.
Time record of sample experiment

Frequency (Hz) vs. Time (mins)

Q Value vs. Time (mins)
Time record of sample experiment

N₂ Pressure( psi) vs. Time( mins)

Cavity Temp( C) vs. Time( mins)

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Problems and Treatments

- System Stability
- Oscillation at low temperature
- Blockage problem
System Stability

- When coolant temperature is changed, the resonant frequency will decay if the system has not stabilized.
- At least 3 hours are needed for the system to stabilize for a 5°C change.
- An efficient procedure is to do multiple salinity measurements at the same temperature.

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Oscillation problem

- Frequency oscillation observed at 0 and 5° C.

- At 0 and 5 degree, the big difference between the cavity temperature and room temperature makes the circulator turned on/off frequently. As a result, the cavity temperature fluctuated periodically.

- Put an insulation on the system can relieve this problem.
The cavity temperature and frequency curves at 0 degree

The fluctuation range of cavity temperature is from 0.06-0.11 °C

Cause 1.2% uncertainty in resonant frequency

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After putting on the insulation

Fluctuation range of cavity temperature is 0.08-0.088 °C

Resonant frequency curve becomes flatter

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The Blockage Problem

- Capillary tube with 0.1 mm inner diameter can be blocked by small dirt particles.

- Previously used sulfuric acid to clean the tube. Method is not always effective. Removal of the tube for external cleaning sometimes leads to breakage.
Treatments for the blockage problem

Oxidizing Acid
(Chromic-sulfuric Acid)
New Experimental Results

- Graphs of the data are drawn by connecting measurement points with straight line segments. Each measurement point represents the average of three or more measurements.

- A “mean” and “variance” is computed for each measurement point.

- Graphs compared with Kline-Swift Model (KS) and Meissner-Wentz Model (MW).

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New Measurements since 2010

- New Methanol purchased from Sigma-Aldrich, 2011
- New Seawater purchased from OSIL (Ocean Scientific International ltd), 2011
- Initial methanol calibration measurements.
- Seawater Measurements (5 degree increments):
  - 30 psu: 0 ~ 35 °C  New Seawater
  - 35 psu: 0 ~ 5 °C  New Seawater
  - 10 ~ 35 °C  Old Seawater
  - 38 psu: 0 ~ 35 °C  New Seawater
- Final methanol measurements.
Real Part of Seawater Dielectric Constant (30 psu)

30 Psu Dielectric Constant Results (Real part)

Real Part

T(C)

1% Error
Real Part of Seawater Dielectric Constant (30 psu)

30 Psu Dielectric Constant Results (Real part)

1% Error

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Imaginary Part of Seawater Dielectric Constant (30 psu)

30 Psu Dielectric Constant Results (Imaginary part)

- Imaginary Part vs. T(C)
  - 1% Error
  - GW

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Imaginary Part of Seawater Dielectric Constant (30 psu)

30 Psu Dielectric Constant Results (Imaginary part)

- KS
- MW
- GW

1% Error
Real Part of Seawater Dielectric Constant (35 psu)
Real Part of Seawater Dielectric Constant (35 psu)
Imaginary Part of Seawater Dielectric Constant (35 psu)
Imaginary Part of Seawater Dielectric Constant (35 psu)
Real Part of Seawater Dielectric Constant (38 psu)

![Graph showing the real part of seawater dielectric constant as a function of temperature(Celsius). The graph includes error bars and a line representing the GW model. The x-axis represents temperature in Celsius, ranging from -5 to 40. The y-axis represents the real part of the dielectric constant, ranging from 66 to 78. There is a 1% error indicated on the graph.](image-url)
Real Part of Seawater Dielectric Constant (38 psu)
Imaginary Part of Seawater Dielectric Constant (38 psu)
Imaginary Part of Seawater Dielectric Constant (38 psu)
Error reduction in Seawater Measurements

The Standard Deviation of Seawater with 30psu Salinity

<table>
<thead>
<tr>
<th>Temp.</th>
<th>Real Part</th>
<th>Imag. Part</th>
<th>Real Part (old)</th>
<th>Imag. Part (old)</th>
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<td>0</td>
<td>0.11</td>
<td>0.23</td>
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<tr>
<td>5</td>
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<td>0.21</td>
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<td>0.34</td>
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<td>0.15</td>
<td>1.45</td>
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JPL Cal/Val workshop, Nov 2011
Error reduction in Seawater Measurements

The Standard Deviation of Seawater with 38psu Salinity

<table>
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<th>Temp.</th>
<th>Real Part</th>
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<th>Real Part (old)</th>
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<td>0.69</td>
<td>0.97</td>
<td>1.78</td>
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</table>
Conclusion

- More accurate new measurements have been made.
- Temperature range has been expanded to include 0 and 5 degrees.

Future Work

- Complete measurements set (35 psu).
- Investigate frequency pulling effect due to the interaction of capillary tube with exit holes in cavity covers.