Testing/Experimental Methods

Four stages of experimental testing were used to evaluate the sensor’s performance. An overview of the goals for each stage is presented below, followed by a more detailed description of the testing method.

Stage one evaluated basic operation of the sensor in order to confirm that the until-then hypothetical sensing method was legitimate. Questions answered by stage one testing included:

* Can the sensor differentiate between water of different conductivities (i.e. does the sensor work at all)?
* Do measurements drift over time?
* Do different salts in the water effect measurements?
* What is an optimal operating frequency?

Stage two evaluated the sensor’s susceptibility to interference of various kinds, along with basic waterproofness and robustness testing. Some questions answered by stage two included:

* Is the sensor subject to interference from:
  + Metal objects near the sensor
  + People
  + Vibration
  + Orientation of its input feed cables
  + Orientation of the sensor
  + Liquid-air boundaries
* Does the sensor leak if left for an extended period of time?
* How does the sensor hold up to mechanical impact and stress? (i.e. What happens if the sensor is dropped and then run over by a 55 gallon drum on a dolly?)

Stage three evaluated the response of the sensor to different levels of water conductivity and attempted to gather data to draw calibration curves. Stage three testing also featured comparison with a conventional commercial water conductivity probe. In addition, some prototype code on the Tsunami board was tested in an attempt to do data collection, processing (ie. conversion of capacitance measurements to conductivity values), and data logging all on a single platform in real time. Some questions answered by stage three included:

* What is the characteristic response of the sensor?
* What does a calibration function for the sensor look like?
* How does the sensor compare to a commercial resistance-measuring conductivity sensor?
* Is it feasible to control all aspects of a sensing system for this sensor on a single microcontroller?

Lastly, stage four directly measured electrical properties of the sensor using an impedance analyzer. The purpose of this stage of testing was to measure the impedance of the sensor in various configurations, and use this information to calculate equivalent lumped-element capacitance and inductance of the sensor. These values are important for fine-tuning the theoretical computational model of the sensor. Some questions answered by stage four included:

* What is the series and parallel capacitance between the input and output of the sensor?
* What is the series and parallel inductance between the input and output of the sensor?
* What is the ohmic resistance between the input and output of the sensor?
* What are the values of the above parameters within the input and the output alone?

Below follows a further description of each testing stage.

STAGE 1: Jar Testing

Stage 1 testing was relatively unstructured.

For all stage 1 tests, the sensor was driven by function generator which generated a 100ms sinusoidal sweep, typically from 100Khz to 5Mhz. The magnitude of the input sweep ranged from 1Vpp to about 10Vpp. The output from the sensor was read on a digital oscilloscope.

For the first set of tests, three pint-sized canning jars manufactured by Ball were filled with distilled water. An arbitrary quantity of table salt was dissolved in one of the jars. One jar of distilled water was designated as a wash jar, and the other distilled water jar was designed the negative control. The sensor was first rinsed in the wash jar, then dipped into the control jar. The shape and magnitude of the output waveform was noted, then the sensor was dipped into the jar with the salt water. Observations were noted again. This process was then repeated several times, occasionally with different sweep parameters. This testing process confirmed that the output of the sensor does vary, at least coarsely, with water conductivity.

For the second set of tests, the sensor was suspended in a single jar filled with a table salt solution of arbitrary concentration. The setup remained static for 3 days, and the output of the sensor was noted at regular intervals. Water was occasionally added to the jar to make up for water lost by evaporation. This experiment was then repeated with distilled water, and also one other salt solution of much higher concentration. The testing process confirmed that the output of the sensor does not vary significantly with time, though the little variation that was found is consistent with the effect of temperature changes on water conductivity.

For the third set of tests, two jars of salt solutions were prepared. One jar contained an arbitrary sodium chloride solution, and a second jar contained an arbitrary sodium nitrate solution. As expected, the sensor showed a difference in output for each, compared with distilled water. It was possible to add sodium nitrate to the second jar until the output of the sensor was nearly identical to the output obtained with measuring the sodium chloride solution. This process confirmed the expectation that the sensor does not discriminate between dissolved ion species.

The final set of stage 1 tests was used to find an optimal input frequency for the sensor. The sensor was immersed in DI water and then fed with the normal 100Khz to 5Mhz sinusoidal sweep, while a digital oscilloscope was used to monitor the output. A frequency was found within the sweep for which the sensor had the greatest output magnitude; this frequency was recorded as a frequency of interest for future tests.

STAGE 2: Barrel Testing

Stage 2 testing utilized the same signal chain as the stage 1 tests. However, instead of glass canning jars, all tests took place using a plastic 55 gallon drum filled with tap water. Unlike previous tests where the sensor was merely dipped into the test liquids, in stage 2 tests the sensor was fully submerged in the test liquid.

All stage 2 tests followed a similar protocol: The sensor was submerged in the water in the barrel, about 4 inches below the surface. The output of the sensor was then observed. The sensor was then treated to a test stimulus, and the output of the sensor in the presence of the stimulus was then observed. Below is a list of tested variables, along with a brief description of each test.

* Metal objects near the sensor
  + A steel butter knife was submerged in the barrel next to the sensor and moved around
* People
  + A hand was submerged in the barrel next to the sensor and moved around
* Vibration
  + The output of the sensor was observed during a prolonged period of vibrations created by a forklift adjacent to the laboratory
* Orientation of its input feed cables
  + The position of the input feed cables were altered while observing any changes in the sensor’s output
* Orientation of the sensor
  + The orientation and position of the sensor was altered while observing the output of the sensor
* Liquid-air boundaries
  + The sensor was moved near the surface of the water and the sides of the barrel while the output of the sensor was observed
* Time
  + The sensor was left in the barrel for one week during a university holiday. Output of the sensor after the holiday was compared to output of the sensor before the break.
* Mechanical impact and stress
  + The sensor was dropped on a concrete floor from an elevation of about 5 feet. This was followed by treatment with an impact from a loaded drum dolly at low speed. The sensor assembly was then visually inspected for damage or deformation, after which an observation of the output of the sensor was then compared to the output of the sensor before the impact.

STAGE 3: Beaker Testing

Stage 3 testing utilized a more advanced signal chain compared to the stage 1 and 2 tests. The sensor was driven by the Tsunami board with a sinusoidal signal at 6Vpp (approx.) for 1 second. In some tests, this signal was followed by a second signal at a different frequency with a duration of 1 second. After a brief pause (10 ms), this would then repeat. The output of the sensor was read by the Tsunami board input circuitry. For each 1 second sense pulse, the Tsunami was programmed to obtain 100 magnitude readings spaced 10 ms apart. These readings were then averaged and output to a laptop in a human-readable format (LSBs) via the serial terminal.

All tests took place in a 3.5L Pyrex beaker at approx. 24 degrees Celsius. A {COMMERCIAL THINGY HERE} which provided standard conductivity and temperature measurements was used as a control and measurement reference point.

The object for the first set of tests in stage 3 was to obtain a rough idea of the response of the sensor to varying water conductivity. Thus, the sensor was set to read with a single probe frequency of 1.52 MHz in the first test, 1.0 MHz in the second test, and 0.8Mhz in the third test. The protocol for the tests was as follows:

The 3.5L beaker was filled to the 3.5L line with DI water, and an arbitrary quantity of Magnesium Chloride Hexahydrate road salt (kindly donated by the Tate Hall maintenance crew) was added to the water. The solution was stirred until the salt completely dissolved, and then temperature and conductivity of the solution was measured using the {COMMERCIAL THINGY HERE}. The sensor under test was then submerged in the liquid, and the reading from the sensor recorded. The {COMMERCIAL THINGY HERE} and the sensor were never in the beaker at exactly the same time, as the 1.52 MHz probing frequency of the sensor interfered with the {COMMERCIAL THINGY HERE}. Each data point consisted of a conductivity measurement, a temperature measurement, a measurement from the sensor under test, and the frequency (or frequencies) used for probing the sensor. After measurements were recorded, an additional arbitrary amount of salt was added and the process repeated. This occurred until the conductivity of the water became very high, at which point the entire process was repeated from the beginning after washing all equipment with DI water. After a sufficient number of data points was gathered, the next test would begin.

The object for the second set of tests in stage 3 was to obtain a set of calibration curves for the sensor using two-frequency probing. The frequencies chosen for probing were 1.52 MHz and 0.8 MHz. The protocol for the second set of tests in stage 3 was identical to the protocol for the first set of tests (above), except that each data point contained two measurements from the sensor under test (one for each probing frequency).

The object for the last set of tests in stage 3 was to test software developed using the calibration curve drawn from the two-frequency probing data. This software was meant to let the sensor output a real conductivity value instead of a measurement in arbitrary units. This very brief period of testing involved a similar protocol as previously described, except this time the {COMMERCIAL THINGY HERE} was used as a control against the sensor under test rather than as a calibration standard.

STAGE 4: Impedance measurements

Stage 4 testing involved the use of a {NAME OF DAN’S IMPEDANCE MACHINE HERE} exhumed from the basement home of an occult anarchist. Although this device was of questionable provenance and required occasional profanity-laced percussive maintenance, reasonable measurements were probably obtained. It is likely that the last time the instrument was calibrated, the Berlin Wall was still standing. Unfortunately, budgetary constraints made the use of an alternative instrument impossible.

The protocol for stage 4 testing was unstructured because of the unpredictable nature of the instrument. Various configurations of the sensor were repeatedly measured at various frequencies using the machine and the measurements were written down by hand. Data points were frequency-dependent vector impedance measurements with magnitude in ohms, phase angle in degrees, and frequency in Hertz.