Discussion of design properties and application strategies

As can be seen from Figure 1.0, the sensor response curve appears as one would expect given the design of the sensor as a tank circuit behaving as a band-stop filter. As a reminder, a sinusoidal signal of fixed amplitude is applied to the sensor as an input, and the output from the sensor is the same signal shape as the input signal, but with a change in amplitude relative to water conductivity. Specifically, as input frequency remains constant and the capacitance of the sensor changes relative to water conductivity, the output magnitude changes. In the development of this sensor, the output magnitude was measured by the Tsunami board.

For every operating frequency, there is one water conductivity value that corresponds to a minimum output response. From Figures 4.1, 5.1a, and 5.1b it is also easy to see that this minimum (or “trough”) is frequency dependent: The minimum appears at a lower water conductivity value as the frequency decreases. Thus, the whole response curve shifts directly dependent on frequency.

Unfortunately, the response curve of the sensor is a many-to-one function, which by definition does not have an inverse function. An inverse function, (such as one that might be useful as a calibration curve to calculate conductivity from the sensor’s output), would fail the vertical line test because a given input would have multiple outputs. Thus, for some of the possible output values from the sensor there are two corresponding possible conductivity values.

Two solutions to this problem have been considered. The first and most obvious solution is to select an operating frequency such that the trough occurs at the minimum expected water conductivity (which can be assumed is 0 uS/cm in most cases). Thus, if we ignore parts of the response curve that correlate with negative water conductivities, the response curve can be considered a one-to-one function instead of a many-to-one function. An implementation of this solution would involve greatly lowering the operating frequency of the sensor.

The problem with this approach can be deduced from Figure 4.1. As operating frequency decreases, the response of the sensor output becomes *less sensitive* (especially at higher conductivity levels); that is, the response function becomes flatter as frequency decreases. Besides decreasing dynamic range, this loss of sensitivity would also increase relative error. If the magnitude of uncertainty in the measurements remains constant , a shrinking dynamic range would increase the proportional uncertainty of the measurements. For example, let’s say that the sensor has a frequency independent uncertainty of ±3 units. At frequency A, the sensor has a dynamic range of 100 units (that is, the lowest possible measurement is 0 units, and the highest possible measurement is 100 units) and so the uncertainty in measurement is ±3%. At frequency B, if the sensor has a dynamic range of 50, the uncertainty in measurement now becomes ±6%.

This problem is further compounded by the nonlinear sensitivity of the sensor. If 60% of the dynamic range of the sensor represents only the first 25% of the expected range of measurable water conductivity values, uncertainty becomes greatly magnified as water conductivity increases.

The second solution considered avoids the previously mentioned pitfalls by maintaining the operating frequency around its most optimal value. Instead, the response curve of the sensor is split into two independent functions around the trough (example: Figure 1.1 and 1.2). Because they are one-to-one, each of these half-functions can be inverted to form two respective calibration functions. However, this does not change the fact that many (if not all) values for water conductivity will correspond with two values – one for each half-function. There must be a way to decide which half-function is to be used for a given measurement, and by logical necessity this way must involve a third variable.

This ideal third variable is phase. In an ideal band-stop filter, there is a phase inversion at the resonant frequency of the filter. For this conductivity sensor, we would expect this phase inversion to occur at the trough. In real world applied terms, this means that we would expect a negative phase shift between the sinusoidal signal input and the output from the sensor to the left of the trough, and a positive phase shift to the right of the trough. Thus, it becomes easy to decide which half-function to use is phase is also measured: if phase is negative, the half-function to the left of the trough is used. If phase is positive, the half-function to the right of the trough is used.

Sadly, due to budget and time constraints, it was not possible to implement phase measurements that effectively coordinated with the magnitude measurements made by the Tsunami board. The makers of the Tsunami board claims that it is able to measure phase, but in practice phase is only reported as an absolute magnitude without sign. This fact renders the phase-measuring capabilities of the Tsunami board useless for this application.

A less ideal third variable is frequency. Luckily, the Tsunami board is able to control and measure frequency with a useful degree of accuracy.

STUFF ABOUT DUAL FREQ MEAS HERE

MODELING OF CURVES USING CURVE FIT SOFTWARE

STUFF ABOUT HOW THE TSUNAMI BOARD AMPLITUDE IS POORLY CONROLLED AND EFFECTED BY

FREQUENCY

MICROCONTROLLER LOAD

USB PORT ☹

ATTEMPT (REFER TO CODE)

DESCRIPTION OF CODE

WHY IT DIDN’T WORK

POOR ACCURACY OF TSUNAMI

CURVES ARE TOO SIMILAR

MODELING IS NOT GOOD ENOUGH