Implementation

From the previous section, it can be seen that there are several components critical to the electrical design of this sensor:

* Conductive material to form the legs
* Insulating material of very uniform thickness and stability to cover the legs
* Electrical components to form the tank circuit
* Circuitry to produce the sinusoidal signal fed to the sensor
* Circuitry to read the magnitude of the signal output from the sensor

The first two points were tackled by the use of magnet wire. Magnet wire is copper wire commonly used to form the windings on electromagnets or transformers. It is produced in a variety of thicknesses and with different insulating coatings to suit various industrial applications, and these properties are standardized and well-controlled by manufacturers. In addition, magnet wire is very cheap, easy to manipulate by hand, and relatively easy to solder to. Luckily for this project, there was magnet wire available at hand that came manufactured with a coating resistant to degradation by water.

For the third point, it was found by chance that the configuration of the magnet wire itself in the prototype sensor (in combination with a single resistor and the coaxial cables used to connect it to test equipment) had enough parasitic inductance to form a tank circuit with a reasonable resonant frequency when considered with the capacitance of the sensor legs.

The last two points were solved by the use of a Tsunami Board manufactured by Arachnid Labs. This board consists of an Arduino-compatible ATmega32u4 microcontroller ganged with a Direct Digital Synthesis chip (AD9838) and a high-speed comparator. Also on board are a reference clock built around a precision crystal, a USB interface, and full-size BNC connectors.

Using the DDS chip, this board can produce a sinusoidal signal of arbitrary frequency between 0 Hz and 2 MHz and it supposedly can vary the magnitude of said signal between 0V and 6V, which made it suitable for producing the input signal for the sensor. The comparator on the Tsunami was also deemed to be useful for reading the output signal from the sensor. The precision temperature-invariant reference clock means that the DDS output frequency is very stable, and the USB interface and microcontroller made for an easily programmable and configurable platform that was thought to be potentially very useful for integrating the sensor into a field-capable sensing system.

Additionally, the Tsunami board is relatively cheap ($60) and completely open source. This means that all aspects of the design necessary to replicate the device (schematics, source code, Gerber files required for manufacturing, etc) are freely available to the public via Arachnid Lab’s Github pages. Since one of the project requirements was to make the sensor easy to replicate by anyone with hobbyist level skills, equipment, and budget, the open source nature of the Tsunami board was very attractive. Also, I happened to have one of these boards in my desk from another project and it was convenient to use.

Of course, there are also practical considerations which necessitated a few more components:

* Some means by which the various electrical parts are connected together
* A mechanical means by which the parts of the sensor are held rigidly and stably together
* Anyone which has ever dropped their phone in a toilet knows that there needs to be some means by which the electrical parts of the circuit that aren’t meant to touch water are kept away from the water

The first point was solved internal to the sensor by using more magnet wire, and external to the sensor by using BNC-connector terminated RG6 coaxial cable. Coaxial cable, usually used for radio applications, was deemed necessary because the resonant frequency range of the sensor fell within the domain of high frequency radio.

The second point was solved in the prototypes by using 1/8 inch thick laser-cut acrylic plastic, cut and hot-glued together into a skeleton for the sensor to be built on. Acrylic plastic has the benefits of being very cheap, widely available, and easy to laser-cut. It has very good insulating properties (and thus does not interfere with the function of the sensor) and is not much effected by water. In addition, acrylic plastic is transparent by default, which is useful for observing potential problems including cracks, leaks, corrosion of the magnet wire (should the insulation fail), and biofouling.

The legs of the sensor and some cabling were additionally secured by the use of plastic zip ties.

The last point was solved in a coarse and primitive (but very effective and fast) manner by potting the entire device (minus the legs) in two-part epoxy resin, using a chocolate candy form from Amazon as a mold.

The total cost of the most current prototype is around $70, including the Tsunami board. Excluding the Tsunami board, and considering the resources and skills of a typical electronics hobbyist (not including theft), the sensor could conceivably be constructed for as low as $0.