WaterMainia Senior Design Project Report

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Abstract—**WaterMainia is a leak detection system installed in a home to detect all ranges of leaks. WaterMainia is a multifaceted flow detection, data analysis and disaster prevention device aimed with preventing catastrophic home flooding via burst pipes, and water conservation through the detection of smaller leaks that would otherwise be undetectable. The device is composed of a Hall Effect flow meter, proprietary software on a single board computer and is being prototyped on a home plumbing simulation. When WaterMainia detects a water flow rate indicative of a leak it will notify the end user via an Android application and shut off water to the home if the leak is severe enough.**

I. Introduction

In the past decades we have been more conscious of water conservation and sustainability than ever before. Homeowners are threatened by water damage caused by flooding and burst pipes. 98% of basements will experience a flood in their lifetime. Repairing the damage of a flood can cost upwards of $8,000 from frozen pipe related failures. In terms of water conservation even a tiny leak can be extremely costly. [1]

Typically homeowners try to solve the issue of flooded basements by installing sump pumps, but otherwise homeowners don't have many options in the way of prevention. Typically floods from burst pipes occur due to oversights and negligence from homeowners neglecting to keep their homes properly heated during the winter. This leads to pipes bursting inflicting large damage upon the home.

Other systems similar to ours are being implemented. However, these systems are very costly (upwards of $2000) and also not market tested. The systems we found similar to ours include WaterHero and LeakDefense.

Water conservation has more or less emerged as a societal issue in the past few decades when concerns of sustainability became apparent. Recently droughts have become of major concern, especially in California, where homeowners can be fined for using too much water. 10% of homes in the United States have leaks that dump out at least 90 gallons of water a day so in drought conditions such homeowners could be heavily fined for a leak they're not even aware of.

Issues with small leaks are generally solved by the user hearing or somehow detecting the leak and getting a plumber to fix it. Fixing a small leak has of late become much easier with the advent of sharkbite fittings which allows pipes to be swapped out faster but identifying that there is a small leak and locating it is very difficult for the end user without any tools. The requirements for our project can be seen in Figure I.1.

WaterMainia also has the potential to be expanded into a leak detection network so that it can more accurately locate and isolate pipe bursts or leaks. In a networked system, flow sensors with shutoff valves would be placed at various points in the plumbing system such as at sink, or other fixture connections and would relay information back to the Raspberry Pi for further processing. Thus, the networked system would allow the user to continue using water without worrying about causing damage to the user's home.

Specification	Requirement Value
Simulate Household Plumbing	¾" Pipe
Close main during pipe burst	Within 1 Minute
Water flow metered+recorded	Tables, Line Charts, Pie Charts
Alert owner of leaks	Any Size
Power Consumption	<50W
Cost	<$500

Figure I.1: Project Specifications

II. Design

A. Overview

Our solution to these problems is to build a system that will detect and record all water flow into the end user's home. Through analysis of the water flow data, the system will detect leaks within the home and alert the owner to the issue so that they may fix it or electronically close a valve that immediately closes the user's water main, thereby stopping any and all water from flowing into the house and alerting the user.

Our system will be comprised out of three main stages, the flow meter stage, the computation stage and the power system stage. The flow meter stage consists of an Hall

Effect Flow Meter which will measure the water flow passing through the water main and into the home.

B. Home-Plumbing Simulation

The Home-plumbing simulation will act to simulate a household water main. To build this block we used our physics and reasoning courses to outline and produce a system capable of simulating city pressure with minimal interference to our water sensing system. Since this design was used to test our waterflow sensor testing of the system included a U.S. Gallon/minute study. And a visual check for air bubbles and backflow.

Our system was connected to a household sink with ¾" PEX pipe. This was implemented in conjunction with a sump pump used to displace water and pressurize our system to within residential household standards.

Figure II.B.1: A picture of WaterMania built into our plumbing simulation.

C. Hall Effect Flow Sensor

Between our Mid Year Design Review (MDR) and our final design, we changed the way which we detect water flow. Up until MDR, we had designed and built an electromagnetic flow sensor as described in Appendix I. However, WaterMania was designed with the intention to be used in a residential setting and although the sensor was implemented successfully; we decided to replace the electromagnetic sensor with a much more cost-effective Hall Effect sensor due to the high cost associated with the components of and shielding for the electromagnetic sensor.

WaterMania's sensor is comprised of a small turbine which is concentric with the axis of the pipe, a permanent magnet attached to one of the tips of the turbine and a p-type semiconductor mounted to the external wall of the pipe. When water flows through the center, the force exerted by the water flowing onto the turbine causes the turbine to spin and thus allows our sensor to exploit the Hall Effect [2] and use the potential difference across the semiconductor to measure the water flow rate.

The Hall Effect is a phenomena which occurs when a magnetic field interacts with current flowing through a conductive material[3]. While a magnetic field is not present, charge is distributed uniformly across the semiconductor; however, when a magnetic field is applied perpendicularly to the semiconductor, a potential difference is created across the semiconductor that is proportional to the magnetic field strength as seen in Equation II.1[3] :

$$V_H = R_H(I/t * B)$$
$$V_H = \text{Potential Difference}$$
$$R_H = \text{Hall Effect coefficient}$$
$$B = \text{Magnetic Flux Density in Teslas}$$
$$I = \text{Current Flow Through the Sensor}$$
$$t = \text{Thickness of Sensor}$$

Equation II.1

Thus, we can measure the potential difference across the semiconductor to help compute the flow rate within the pipe.

Utilizing Equation II.1, our sensor tracks the potential difference across the semiconductor and outputs a 5VDC pulse when the turbine spoke with the permanent magnet attached to it passes by the semiconductor. Thus, the output of our sensor is always either in a low state, 0VDC, or a high state, 5VDC, and we measure the water flow rate by tracking the frequency of DC pulses as described in Section D.1. Since our output is a controlled by the speed at which the turbine is spinning, and in turn is controlled by the force which the water flow exerts on the turbine itself, the lower limit on flow rate detection is set by the amount of force needed to turn the turbine. From our testing, we were able to accurately measure flow down to 0.003(+/-10%) U.S. Gallons/second (0.00075 Liters/second) with measurement accuracy degrading as flow rate decreased below 0.003 U.S. Gallons/second.

D. Water Flow Analysis

The single board computer, Raspberry Pi 3 [4] will receive the DC pulses from the Hall Effect Flow Sensor. It will then count the positive edges of these pulses, calculate the frequency of the pulses every second and then convert said frequency into a volumetric flow rate (U.S. Gallons/minute) as described below. Periodically the device will save the data to a cloud server so that it can be retrieved by the user via an Android Application as described in Section II-E. The data will be placed in a MySQL Database to simplify storage and retrieval. The Raspberry Pi 3 will also periodically analyze the current water flow rate against the system parameters set by the user as well as against past data to determine if a pipe within the home is currently leaking or has burst. It is important to note that the device will have two separate modes of detection: an At-Home and a Vacation mode. The detection mode will be determined by the user via the Android Application as described in II-E. Lastly in the event of anomalous behavior, the Raspberry Pi 3 will alert the user's smartphone and close the device's solenoid valve [5] if necessary.

1) Flow Rate Conversion: As stated in Section C, we are able to calculate the volumetric flow rate through our system by tracking the frequency of DC pulses outputted by the Hall Effect sensor. To do this, our sensor inputs its output into our analog to digital converter, the MCP3008 IC [6]. The MCP3008 IC then digitizes the signal and passes the signal to the Raspberry Pi via the GPIO pins. The Raspberry Pi then increments a counter on every positive edge detection and averages the frequency across a one minute interval to calculate the U.S. Gallons/minute flow rate. For a reference, 0.25 U.S. Gallons of water consumption is equivalent to 477(+/-10%) positive edge detections and thus a flow rate of 0.25 U.S. Gallons/minute translates to an average frequency of 8Hz. Thus by taking the number of positive edge cycles counted and dividing it by 1908 (477*4) we are able to calculate the total number of U.S. Gallons of water which have flown through the pipe within any particular minute.

2) Saving Data: The volumetric flow rate will be saved onto a remote MySQL database. We have chosen to use a cloud server because it grants the user easier access to their water consumption data by allowing WaterMainia to store a larger amount of the user's consumption data as well as allows the user to access their consumption data without the user forwarding ports to WaterMainia. In the event that WaterMania was to be accessed remotely by the user, WaterMania would have to act as a server and thus would need to have port 80 forwarded to the device. Aside from the obvious problem of forwarding ports being confusing for the average user, it can also open vulnerabilities in the user's network if they do not know what they are doing and thus deters us from allowing direct access to the WaterMania device.

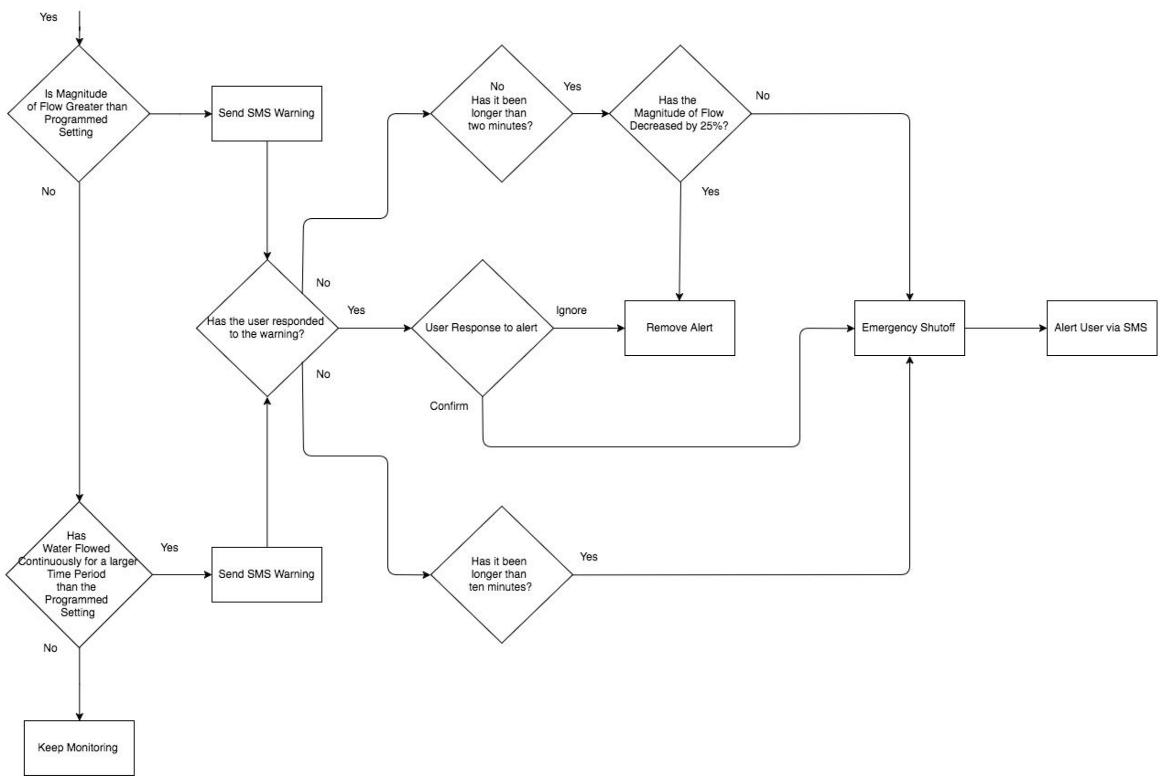


Figure II.D.1: At-Home Mode Pipe Leak and Burst Detection Logic

The volumetric flow rate will be uploaded to the server database every 60 seconds. The data will be saved within the MySQL database in two fields: U.S. Gallons per Minute and a Time Stamp. The Time Stamp will allow the user to download and display their water consumption via the accompanying Android Application as described in II-E.

3) At-Home Mode Detection: If the user has the device set to At-Home Mode, then the device first compares the user's current water consumption against two user defined parameters: the maximum continuous flow duration and the maximum flow magnitude. These parameters are set by the user from within the Android App. If either of these rules are broken then the device will then proceed with the appropriate actions as seen in Figure II.D.1 and as described below.

The rule regarding water flow duration primarily targets the loss of water due to small leaks. In the case that water has flown through the pipe continuously for longer than the duration set by the user, WaterMania will proceed to first warn the user of the possible pipe burst and then wait ten minutes for the user to respond to the initial warning via the Android App. If the user does not respond within the ten minute warning window then the system will close the emergency shut-off valve and alert the user of a pipe burst. The decision to first warn the user instead of immediately shutting the valve was made to limit the number of false detections. We also decided to allow a large response window of ten minutes due to the fact that the user is more likely to break this rule during normal water consumption. If at any time before the valve is closed the water flow returns to zero flow then the timer will automatically be reset.

The second At-Home Mode parameter, the maximum magnitude parameter, is meant to respond to large pipe bursts. In this case, if the water flowing through the system is of higher magnitude than the value set by the user, then the user will again first be warned of a potential burst. If the user does not respond to the alert within two minutes then the emergency shut-off valve will be closed and the user will be alerted of the shut-off. It is important to note that the maximum magnitude rule must be broken for two consecutive minutes before the initial warning is sent to avoid a false positive. After the alert is sent, if the maximum magnitude of water flow goes below 50% of the maximum magnitude parameter then the alert will be reset automatically

4) Vacation Mode Detection: When the user is away from home he has the ability to switch WaterMania into Vacation Mode. In Vacation Mode, WaterMania will treat any change in water flow rate as a potential pipe burst or leak and will immediately shut the solenoid valve and notify the user to mitigate damage.

E. Android Application and Remote Access

The Android Application as well as the cloud server has been designed to enable the user to intuitively use WaterMania and access their water consumption data. The reason an Android Application was chosen is to allow the user to be able to remotely control WaterMania and receive alerts even when they are not home. While the cloud server was implemented to allow the user to access their water consumption data even when their device is temporarily disconnected from the internet and to remove the need to forward your router's ports to WaterMania.

1) Android Application: As seen in Figure II.E.1, the Android Application for WaterMainia features two main activities: the View Water Usage Activity and the Settings Activity. In Figure II.E.2, you can see that the user is presented with two sets of date and time pickers. These date and time pickers allow the user to choose the period of time which they want to retrieve their home's water consumption data. The first set of date and time pickers is for the start date and the second set is for the end date. Upon picking your desired time interval and hitting submit, a request to run a PHP script is sent to the cloud server and the data is then echoed back from the MySQL database to the user's application.

Figure II.E.1: Main Menu

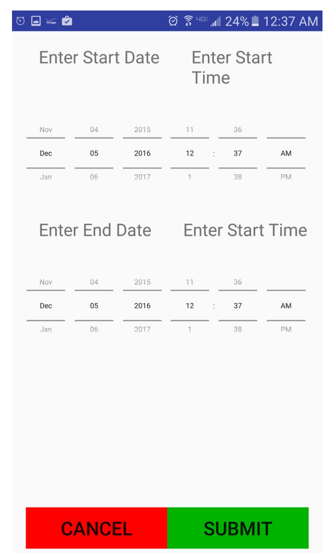


Figure II.E.2: Date Selector

Upon receiving the data, the android application compiles said data into three types of graphs which are capable of displaying varying information about your water consumption as seen in Figure II.E.3.

Graph Type	Time Stamp	Flow Rate	Total Water Usage

Table	x	x	x
Line	x	x	x
Scatter	x	x	x

Figure II.E.3: The types of graphs included in the Android Application and their contents.

The first type of graph is a table much like the one pictured above in Figure II.E.3. The table will consist of four columns: timestamp, volumetric flow rate, and cumulative water usage where the first entry is the initial time selected and the last entry is the final time selected on the previous screen. Figure II.E.4 gives a description of what each column contains.

Column Title	Description
Time Stamp	Contains the date and time which a particular entry corresponds to.
Volumetric Flow Rate	Contains the water flow rate at a particular time in U.S. Gallons per Minute
Cumulative Water Usage	Contains the total amount of water which the user has used since the start of the time period in U.S. Gallons (The first entry will have 0 gallons used).

Figure II.E.4: Android Application Table Column Description

The Line Graph, Pie Chart and the Scatter Plot's data descriptions are the same as the Table's data description in Figure II.E.4, however the Line Graph visually displays changes in flow rate, and water consumption individually while the Scatter Plot will overlay the volumetric flow rate on top of the total water consumption across the inputted time period . Although the Scatter Plot does encompass all of the information which the Line Chart does, we have decided to include both types of graphs because the two graphs compliment each other's strengths and weaknesses. That is that the Line Chart does a better job at displaying trends in data points when there are less data points, while the Scatter Plot does a better job at displaying trends amongst large amounts of data.

The second Activity, the Settings Activity, is where the user remotely controls WaterMania from their Android Device as seen in Figure II.E.5. From this screen, the user can remotely control the device's solenoid valve by either overriding the solenoid's state to open or close, or by allowing WaterMania to control the solenoid. Next, the user can set the device's current mode of operation to either At-Home Mode or Vacation Mode.

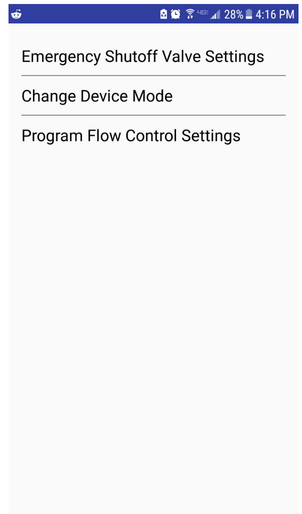


Figure II.E.5 Settings Activity

Lastly, the user can set their At-Home Mode parameters via the Program Flow Control Settings Button.

2) Cloud Server: We are currently using HostGator as the service for the cloud server as it allows us to host a MySQL database as well as run PHP scripts remotely. Inside the server a MySQL database contains all of the flow data dating back until the start of the device where each entry consists of four fields: a time stamp, volumetric flow rate, a boolean determining if an alert was sent and a string which contains what type of alert was sent.

However, the cloud server does not solely act as a point for data retrieval, but also acts as the middle-man for transferring commands between WaterMania and the user's Android Application. From WaterMainia's end, WaterMania polls the server every 60 seconds to check for any settings changes made by the user. It does this at the same time that data is uploaded so that the device does not have to separately connect to the server and thus wastes as little processing power as possible. If a command is found then the command is downloaded and executed by the device and is then deleted from the cloud server. WaterMania also routes all push notifications through the server by running a PHP script located on the cloud server to send the alert to the user's Android Device.

From the Android Application end, the Android Application pushes all commands onto the cloud server where they will be stored until the user's device polls for the commands.

F. Solenoid Valve

We chose to implement our water main shutoff with an electronic solenoid valve controlled by a solid state relay. This valve is being driven directly from a residential standard 120VAC receptacle. For convenience and with power consumption in mind we chose US Solid Solenoid Valve. [7] This valve only has an 18W power rating and manual override providing safety for our system. With temperature tolerances of 14-248 degrees fahrenheit we are well within our extreme tolerances of residential water temperature, making this valve a perfect fit. Simulations and testing proved this valve to be exactly what we needed.

G. Power System

The power system chosen to drive Watermania is sourced by a standard 120Vac receptacle. 120Vac from wall outlet is stepped down via a center tap transformer creating two, 7V and -7V, rails. We use a 3A bridge rectifier and two sets of smoothing capacitors to generate a smooth DC signal. Two regulators (lm7805[8], lm7905[9]) follow the Dc conversion to create reliable voltage for our system. The raspberry pi operates on 5VDC as well as the hall effect sensor. Our output signal from the hall effect sensor was not strong enough for the the Raspberry Pi to interpret and therefore needed to be amplified using a noninverting op-amp configuration with gain Av=1.5. Our RC4558 op amp needed Vss, -Vss at 5V and -5V respectively. Due to heat loss, wire loss, and chip factors our actual amperage draw from receptacle was .16A leading to a power consumption of 18W.

	Voltage	Amperage	Power
Raspberry Pi	5V	.3A	1.5W
Hall Effect Sensor	5V	.05A	.25W
Solenoid Valve	110V	.16A	18W
Total			19.75W
Actual			34W

Schematic of power system can be viewed in Appendix III.

III. Project Management

During the development of WaterMania an already challenging task became even more difficult as two of the three members of our group, Greg Boudreau and Mike Moran, had full-time jobs on top of attending school. However, despite the adversities, our team was able to continuously adapt to an ever changing schedule and ultimately stick to our schedule as described in the Gantt Chart in Figure III.1 by constantly communicating as well as by utilizing video meetings in addition to our weekly group meetings with Professor Hollot.

The team members of Watermania complimented each other well as each of our expertise lay in different fields. Greg Boudreau was the project manager and was responsible for the design of the electromagnetic coils used in the previous version of WaterMania as well as for the design of all of the different software components. Greg programmed the system's logic, the Android application, and the communication between WaterMania, its server and the Android App. Mike Moran used his vast experience in power systems and hardware to completely design the power system in the final system as well as in the much more complicated electromagnetic system. In the electromagnetic system, Mike also made large contributions to building the coils as well as the design of the system's plumbing simulation. Lastly, Jonathan McAvoy was tasked with building the printed circuit board (PCB).

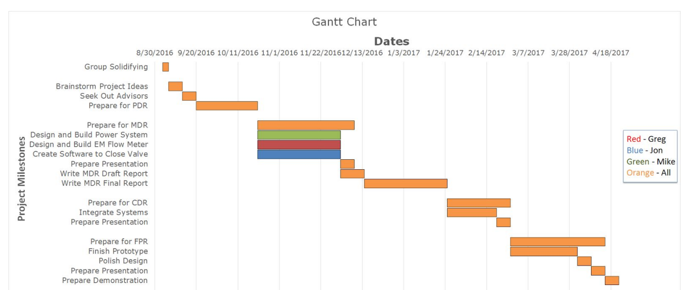


Figure III.1: Gantt Chart

IV. Conclusion

Our final project consists of a simulation system built with the flow meter fastened onto it and the flow meter's output feeding into the computation system and a solenoid acting as our emergency shut-off valve. We have accomplished all of the goals we set out to achieve in our project. We are able to accurately track the flow of water using a Hall Effect Sensor. Our single board computer is counting the positive pulse edges outputted by the flow meter and communicating with the solenoid valve. Our system responds to its rules within the appropriate amount of time and closes the emergency shut-off valve when necessary. The system is fully integrated with the remote server to communicate between the user's Android device as well as to save data onto the server. Pending a few minor improvements to compact the system as well as introducing security measures to client-server communication, WaterMania is ready to enter the residential market.

Appendix I

Electromagnetic Flow Sensor

WaterMania measures the user's water consumption using an electromagnetic flow sensor. This sensor is comprised of two electromagnetic coils which are placed on the top and bottom of the pipe. The coils create a uniform magnetic field within the pipe which polarize the ions in the water within the pipe which in turn creates a potential difference within the water. The two electrodes which are set into the pipe perpendicular to the electromagnetic coils, as seen in Figure II.C.1, allow WaterMania to output the potential difference to the amplification and filtration component of the sensor, as seen in Figure II.C.2, which in turn outputs a voltage to the MCP3008 [6] analog to digital converter. Lastly, the MCP3008 outputs a digital voltage reading to the Raspberry Pi 3 for further processing as described in Section II.D. The graphs for each signal are displayed after their corresponding sections: electrodes, amplification, filtering.

1) Electromagnetic Coils: The two electromagnetic coils are configured as Helmholtz Coils. The reason for using the Helmholtz Coil configuration is that Helmholtz coils create a uniform magnetic field between the two coils, as seen in Figure II.C.3, which is vital to sensor accuracy. An air cored coil is used in WaterMania to further eliminate inaccuracies which would occur if an ferromagnetic material were to be used such as an iron core. In turn this forces us to use higher amperage to make up for the magnetic field strength added by an iron core.

In the Helmholtz configuration, the two coils are placed along the same vertical axis spaced a distance of their

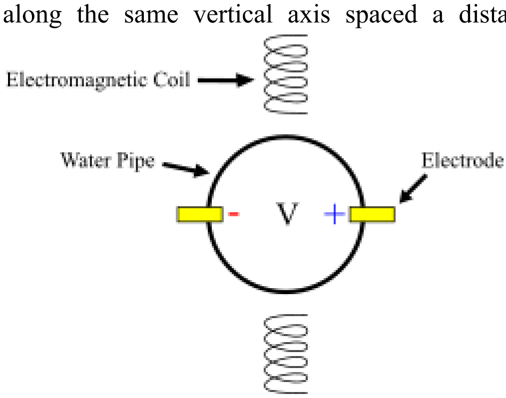


Figure II.C.1: A cross-sectional diagram of the sensor layout. Two coils are placed on top and bottom of the pipe which create a potential difference in flowing water. The difference is then measured by two electrodes placed perpendicular to the coils.

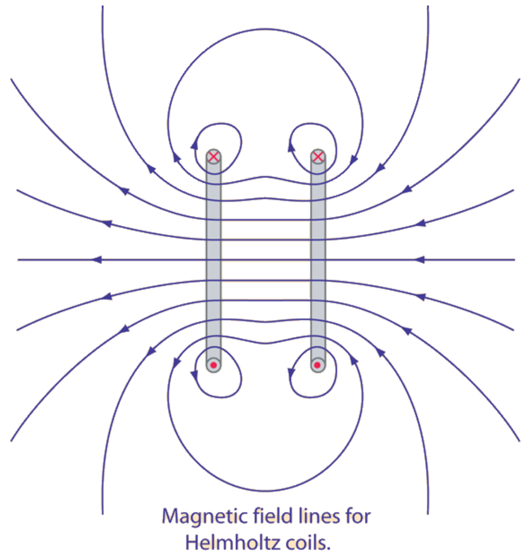


Figure II.C.2: Depicts the uniformity of the magnetic field between two Helmholtz Coils. [10]

diameter apart. The water pipe is centered between the two coils as seen in Figure II.C.1. By centering the pipe between the two coils and having the coils a distance equal to their diameter apart, the equation for their combined magnetic field strength can be simplified to Equation II.1 [11]:

$$B = \frac{32\pi NI\, x10^{-7}}{5(5r)^{1/2}}$$

B = Magnetic Field at Mid-Point (tesla)
N = Number of Coil Turns
I = Amperage
r = coil radius

How the electromagnetic coils are used to measure water flow is based in Faraday's Law. Faraday's Law of Induction states that when a conductor passes through a magnetic field, it creates a potential difference across that conductor. Thus when water, a conductor, flows through the magnetic field created by the coils Faraday's Law can be applied to the system by using equation II.2 [12]:

$$u = kBvd$$

u = Induced Voltage
k = Device Specific Constant
B = Magnetic Field Strength
v = Water Flow Velocity
d = Pipe Diameter

Equation II.2

The necessary magnetic field strength was then calculated by selecting a desired induced voltage, 25 uV, setting the water flow velocity to 12 feet per second, the maximum velocity possible within our system's pipe diameter of ¾ inch. Thus we determine that the necessary magnetic field strength of the coil is 359×10^{-6} Tesla. Knowing the necessary magnetic field strength we can then use Equation II.2 in conjunction with Equation II.3 to determine the Amperage that will run through the coils from our 5 volt supply. The self-inductance caused by the coils, variable L in Equation II.3, is calculated in Equation II.4 [13].

$$V = I((wL)2+R2))\tfrac{1}{2}$$

V = *Voltage*
I = *Amperage*
W = *angular frequency*
L = *Self-Inductance*
R = *Resistance*

Equation II.3

$$L = 2\square * k * N2 * r2/l$$

L = *Self-Inductance*
N = *number of turns*
k = *coefficient of air*
r = *radius of coil*
l = *length of coil*

Equation II.4

The above equations ultimately led to the Electromagnetic Flow Sensor specifications seen in Figure II.C.3.

2) Electrodes: The electrodes chosen for WaterMania's testing phase was 0.1019 mm copper wire. The material was chosen for its high conductivity and its low-cost. However, in future versions a platinized titanium electrode will be used for even higher conductivity as well as for its resistance to corrosion. The electrodes' output is to the instrumentation amplifier describe in section II.C.3.

Specification	Value
Voltage	5V
Amperage	120mA
Magnetic Field Strength	359 uT
Induced Voltage	25uV
Magnetic Wire Gauge	24 AWG
Total Coil Resistance	40 Ω

Figure II.C.3:Electromagnetic Sensor Specifications

2) Electrodes: The electrodes chosen for WaterMania's testing phase was 0.1019 mm copper wire. The material was chosen for its high conductivity and its low-cost. However, in future versions a platinized titanium electrode will be used for even higher conductivity as well as for its resistance to corrosion. The electrodes' output is to the instrumentation amplifier describe in section II.C.3.

3)Signal Amplification: The amplification stage of the Electromagnetic Flow Sensor is a two stage amplifier with a total gain of 1000 times. The first of the two stages is an instrumentation amplifier with a 20db gain as seen in Figure II.C.4. Currently two RC4558P IC [4] are being used in the testing phase to build the instrumentation amplifier. The Op-Amps' on the RC4558P IC specifications are shown in Figure II.C.5. Although a prebuilt instrumentation amplifier will be used in future versions of WaterMania. The reason an instrumentation amplifier was chosen is because it is a differential amplifier as well as it is highly accurate and is the optimal Op-Amp configuration for handling highly sensitive signals due to its high input impedance in excellent CMRR.

The second stage of the amplifier is simply a non-inverting Op-amp with 40db gain as seen in Figure II.C.4.

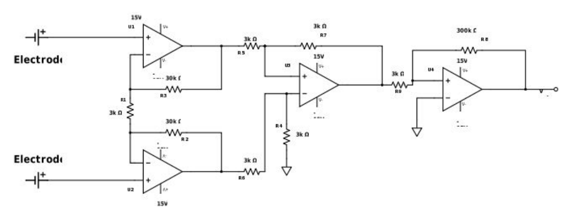


Figure II.C.4: Two Stage Amplifier

Specification	Value
Input Impedance	5MΩ
CMRR	90dB
Vss	15V
-Vss	-15V

Figure II.C.5: RC4558P Specifications

4)Signal Filtering: After amplification there is a lot of high frequency noise to filter out. Thus a four stage low-pass Butterworth filter was built to remove all noise above 100 Hz. In the filtering component the ADA4096-2 IC [14] was used.

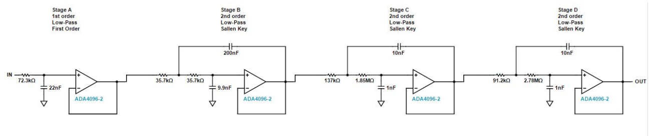


Figure II.C.6: Low-pass Butterworth Filter

Appendix II

Computing Flow Rate for the Electromagnetic Sensor

The ability to determine the current flow rate within the main water line lies within Faraday's Law of Induction as stated in II-C [10]. Knowing this we can use the equation [15]:

$$u = kBvd$$

u = Induced Voltage

k = Device Specific Constant

B = Magnetic Field Strength

v = Water Flow Velocity

d = Pipe Diameter

Equation II.2

In this equation, the induced voltage, u, measured in volts is the potential difference of the ions within the water between the two electrodes created by the magnetic field. The device specific constant, k, is a constant programmed within the device which is determined experimentally to adjust the device for accuracy. The magnetic field strength, B, is the magnetic field strength between the two coils. The water flow velocity, v, is measured in meters per second and is the rate at which the water is flowing through the cross sectional area beneath the coils and between the two electrodes. Lastly, the pipe diameter, d, is the width of the pipe, measured in meters or the approximate distance between the two electrodes.

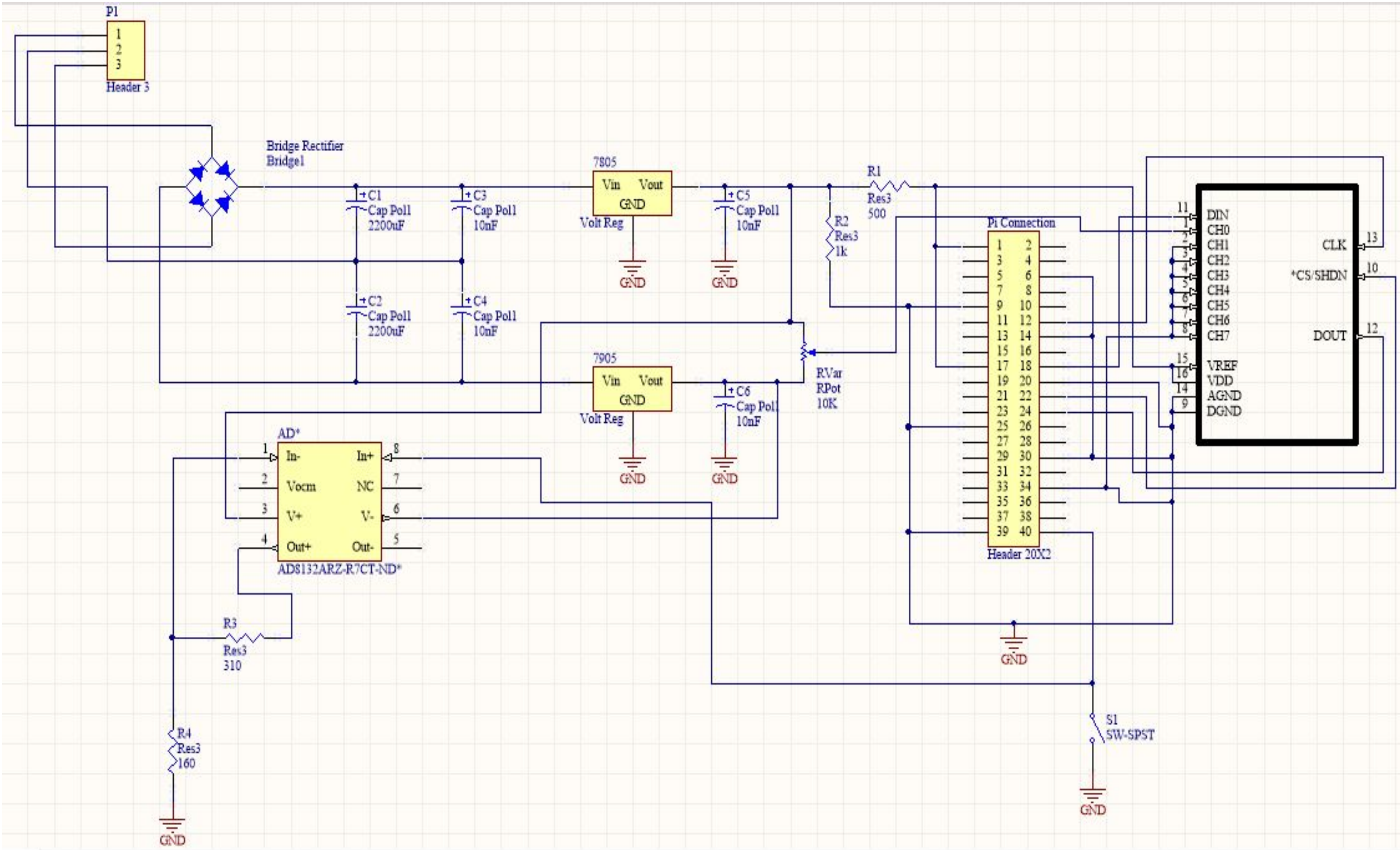
By manipulating equation II.1 we can determine the flow rate of the water in meters per second:

$$v = \frac{kBd}{u}$$

Equation II.2

The velocity of the water found in Equation 2.2 is then converted to a volumetric flow rate by multiplying the velocity by a factor of 0.075295. The new volumetric flow rate is now in units of U.S. Gallons per second.

APPENDIX III



ACKNOWLEDGMENT

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