DEPARTMENT of ELECTRICAL & COMPUTER ENGINEERING

Design Document for

Water Detector

Submitted to:

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TABLE OF CONTENTS

EXECUTIVE SUMMARY

One of the biggest concerns when it comes to aquatic engines is the prevention of water intruding the engine's lower unit chamber. Although the chamber contains seals to prevent the intake of water, these seals are often broken, allowing water to flow freely into the chamber. Seals are most often broken due to the entanglement of fishing line with the engine's propeller. Once a considerable amount of water has entered the lower unit's chamber and mixes with the oil, the threat of damage to the gears and the overall chamber of the lower unit significantly increase. The most overwhelming element of this problem is the cost of engine repair due to the mixture of oil with water in the lower unit. These costs can exceed $1800, depending on the severity of the damage.

The goal of this project has been to design a device that will detect the presence of water once it has entered the lower unit's chamber. The work thus far has led to the design and building of a capacitance sensor that, based on the amount of water present in a mixture with oil, yields a capacitance that correlates with the mixture. Upon testing, it has been determined that the more water present in a mixture with oil, the higher the capacitance value this sensor yields. After recognizing the relationship between the presence of water and the capacitance values, it became necessary to quantitatively perform the analysis of deriving the capacitance readings without the use of high tech lab equipment. This realization led to the design of an oscillator circuit using a 555 timer. This circuit was designed in a manner in which the capacitance sensor acts as one of its capacitors. Therefore, the overall frequency that is produced by the circuit depends on the capacitance yielded by the sensor. Tests have proven that as the capacitance value associated with the sensor increases, the frequency yielded by the oscillating circuit decreases.

The next step has been designing an interface that will be easily interpreted by the occupant of the boat once a frequency that corresponds with the presence of water has been given by the oscillator circuit design. A PIC16F876 is acting as the micro-controller of our design. The PIC has currently been programmed to count the pulses that correspond to the output of the oscillator circuit. Upon further testing, pulse count thresholds will be set that will allow the processor to determine whether the lower unit has been breeched by water. Once a pulse count conducive to the presence of water has been calculated by the PIC, a set of LEDs will be turned on and a buzzer will sound.

Currently, the display panel, oscillator circuit, and microprocessor are all include in a PCB representation of the system. The board was designed where the display panel could be detached and placed near the steering mechanism of the boat for easy viewing by the occupant of the boat. In future weeks, the board will be mounted in a water proof casing. Additionally, all pulse count thresholds will be set which will allow for a completed version of our system.

1. PROBLEM

The original design of the outboard motor dates back to 1881, when Gustave Trouve introduced his “Motor and Screw” at the Paris Exposition. Trouve’s design consisted of an electric motor positioned directly over a rudder. Within the rudder’s frame was a three bladed screw, or propeller, that was driven by sprocket, cogwheel, and chain [1]. In the original design, the gears that drove the “screw” were exposed to the elements. However, in 1885, Samuel H. Jones, revised Trouve’s design by creating an underwater casing that projected the propeller and housed the gears of the unit.

Today in outboard motors a portion of the engine’s housing still extends below the water line so that the propeller can be located below the surface of the water. The power head of the engine delivers power to a drive shaft that is geared to turn the propeller shaft, thus delivering thrust to propel the boat. Additionally, the gears, shafts, and supporting bearings are still contained in a lightweight housing or gear-case to protect them from the surrounding elements of the engine [2]. This casing, often referred to as the “lower unit”, is sealed and filled with oil that provides lubrication to its gears.

One problem that is associated with this type of engine is the intrusion of water into the lower unit’s chamber. This water intake is mainly caused by the degeneration of seals that protect the encasing from its surrounding environment. These seals can be broken many different ways, however, the entanglement of fishing line in the propeller shaft is the leading cause of their destruction. Once a seal is broken, it creates an avenue for oil to escape and water to enter the system.

Water mixed with oil in the lower unit’s chamber forms the possibility of damage to the unit. This damage can include rust or deterioration of the chamber. Also, lack of sufficient lubrication to the gears of the lower unit can cause excessive heat in the casing. If these problems are undetected, engine failure may occur. And depending on the location of the craft, loss of propeller motion can cause a great inconvenience to those on the vessel. Additionally, the costs of engine repair due to the loss of oil and water intake are expensive.

The objective of this project design is to create a sensor system that will detect the presence of water in the housing of the lower unit. This design will consist of a capacitance sensor located in the chamber’s casing. Upon the detection of different capacitance levels, the oscillator will either increase or decrease the frequency due to the variation in capacitance. Capacitance levels change due to the dielectric. Ideally, the dielectric will be pure lower unit oil until contamination occurs. These changes will be consistent with that of water mixed with oil, and a warning light will be displayed to alert the occupant of the vessel. This will allow the said occupant to shut down the engine before critical damage can occur.

Upon initial review of techniques suitable for measurement of the water entering the lower unit, we concentrated our research on the following characteristics of the oil: temperature, density, conductivity, and capacitance. After careful evaluation we concluded that the measurement of capacitance would benefit our design the most.
Since the addition of water will make the capacitance of oil increase, specific limits of how high the capacitance of the oil can reach will be designated in order to accurately alert the users of water contamination.

Currently, there is no such device on the market to detect a breech in the lower unit. Significant repair cost can be greatly reduced if water is detected early enough. Upon the completion of building the detection device, it will be compatible with many different types of outboard motors from various manufacturers. Therefore, interest in a finished product should be noteworthy.

2. OBJECTIVES

The water detector will have a significant impact on boating among marine enthusiasts everywhere. Our product is a sensor system for detecting the presence of water in a sealed oil chamber of a marine engine, and also serves as a warning signal to the boat operator. The main objectives for our design include:

1) Finding a limitation on the amount of water that is allowed to mix with the oil.
2) Designing a system that will have a fast and accurate response time in order to warn the users of the potential damage of too much water contaminating the lower unit.

The sensor assembly will be mounted in the lower unit of the marine outboard. On the lower unit of any marine outboard there are two screws. The lower screw's function is to drain the oil and the upper is used as an air breather. Our product will be mounted in the lower part of the lower unit for the detection of water. In order for our product to be successful, we've come up with the following constraints:

1. **Cost:** Our estimated product cost should not exceed $200.

2. **Weight:** The weight of our measuring device and circuit board is expected to be less than 3 lbs.

3. **Compatibility/Packaging:** Our measuring device will be approximately 3/8" in diameter, and our board will measure about 6" wide, 4" high, and 4" deep.

4. **Readability:** The signal processed to the user should be easily read allowing the

user to interpret the seriousness on the amount of water contaminating the lower unit.

5. **Durability:** An important factor our group must consider is the durability of the product within its working environment. The Water Detector will be exposed to constant vibration in the lower unit.

6. **Power Requirement:** A voltage regulator will be used due to the inconsistency of the voltage source caused by the charging from the stator or alternator.

7. **Electromagnetic Interference (EMI):** Our product will be designed to not be affected or cause interference to other electronic devices in the boat in accordance to the Federal Communication Commission's (FCC) regulation on induced voltage in watts per meter.

8. **LED user interpretation:** One of our major objectives of the design, the LED's will determine how much water has contaminated the lower unit.

9. **Output Latency:** The response time of our board will vary from 1 to 5 seconds. This will also designate the importance of proper reaction from the users.

10. **Capacitance:** In order to measure the amounts of water entering the lower unit, our device will be designed to constantly measure the capacitance of the oil that in return affects the frequency of the oscillating circuit.

Since this is a totally new product, our specifications will change during research. The ability to recognize the constraints of the product will determine its success. In order for our team to succeed with this water detector additional research will be necessary.

2.1 Cost

Since one of our main goals is to guard against the expensive route of interchanging lower units due to water contamination, our price must be comparative. The design of our product will ultimately affect the cost of our product. Lower unit assembles range anywhere from $2199 to $6499, therefore emphasizing the importance of our product design. Our initial target price of $200 should not be difficult to maintain.

2.2 Weight

Weight is an important determining factor in the overall speed of any marine vessel. Another feature of the Water Detector is that it is designed to be light and compact. The weight of our measuring device and circuit board is expected to be less than 3 lbs. This will provide easy installation and it will not interfere with other lower unit devices.

2.3 Compatibility/Packaging

Due to the measurements of our device, compatibility will be a key factor of our product. The compatibility of our product will enable it to adapt to various motors ranging from different sizes (5-225hp) and types (Yamaha, Mercury, Evinrude). The installation process of the measuring device will vary from motor to motor due to the different size lower units; however, the installation of the circuit board will remain the same. As a result of time and cost constraints, we will feature our device using only one engine.

2.4 Readability

Another key feature of our product is that it is designed to be user friendly. The signal processed to the user should be easily read allowing the user to interpret the seriousness on the amount of water contaminating the lower unit. One key deterrent to our product will be too much sunlight not allowing the brightness of the LED's to be visible. We will be forced to counter issues like sunlight in order to make our product as readable as possible.

2.5 Durability

Due to the continuous vibration of the motor in boats, our product must be durable enough to perform accurately within its surroundings. A huge task that our group will deal with is implementing a conductivity sensor that will be able to properly adapt to the environment.

2.6 Power Requirement

Since a 12-V battery powers most boats, our product does not need additional sources of power. However due to the inconsistency of the voltage source caused by the charging from an alternator, a voltage regulator will be used to keep the power supplying our device, constant at 12-V.

2.7 Electromagnetic Interference (EMI)

One aspect of our product that we are concerned about is Electromagnetic Interference. In some cases electronic devices that operate within short distances of each other cause interference in the operation of one another. The Water-Detector should be designed to operate around other electronic devices such as a cell phone, radio, laptop computers, etc.

Some causes of EMI include high clock rate timing pulses used in these devices, and their harmonics.

2.8 LED User Interpretation

One of our major objectives of the design, the LED's will determine how much water has contaminated the lower unit. Ranging from a simple warning to serious water contamination, the LED's will allow the user to always have knowledge about the amount of water entering the lower unit. Through extensive research, our group will determine the different acceptability levels of water in the lower unit.

2.9 Output Latency

One of the ultimate responsibilities of our product is to alert the user of water entering the lower unit of the boat. Our group has estimated that a respectable response time for the sensor to alert the users is in the range of 1 to 5 seconds. As a group, we must find a sensor that achieves our ultimate goal of alerting the users.

2.10 Capacitance/Frequency

One huge aspect of our research is determining how to measure the water entering the lower unit. After preliminary research we have chosen to constantly measure the conductivity of the oil contained in the lower unit. Due to the polarization, and various inconsistencies of water, this approach was a failure. The only feasible approach is measuring the capacitance of the oil. Since the addition of water will make the capacitance of oil increase, we will designate specific limits of how low the frequency of the oil can reach before the sensor alerts the users. These specific limits will be determined with more accurate research and testing.

3 APPROACH

The following sections will give a detailed explanation of the hardware components of our system.

3.1.1 Sensor

Our sensor was constructed to measure the capacitance of oil, water, or a dielectric. Also, our sensor will be wired directly into our oscillating circuit to produce a certain frequency due to the dielectric within the capacitor. In its simplest form, a capacitor consists of two conducting plates separated by an insulating material called the dielectric. The capacitance is directly proportional to the surface areas of the plates, and is inversely proportional to the separation between the plates. Capacitance also depends on the dielectric constant of the substance separating the plates. The sensor system of this project is the equivalent of a capacitor. This sensor was constructed and tested by using the fundamental principle of a RC circuit. This RC circuit is shown below in Figure 3.1.1.1.

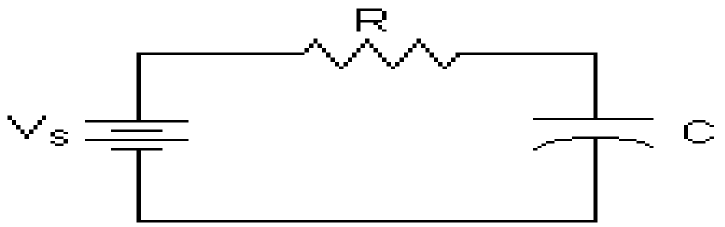


Figure 3.1.1.1

The construction of the sensor consists of one ½ inch copper tubing, two copper male adapters, two plastic female adapters, one rubber washer, one washer, one .625 inch copper tubing, one .123 inch copper tubing, two solid conductor #14 wire, and one copper fitting.

In order to construct the sensor, 4 inches of ½ in. copper tubing was heated and the two copper male adapters were placed on each end of the tubing. The copper had to be cleaned at both ends, and then flux was brushed on both ends. After the flux was applied, both male adapters were placed and soldered.

Next, the copper fitting had to be mounted within the plastic female adapter. The plastic adapter had to be sanded on the inside to accommodate the larger diameter washer. This washer was placed in the plastic adapter and epoxy was applied. Once the epoxy dried, it formed a mounting section for the copper fitting. The plastic adapter was then screwed on the ½ in. copper tubing with the rubber washer separating them. The copper fitting was then mounted to the washer. This would allow the .625 in. copper tubing to be secured by the copper fitting within the ½ in. copper tubing. Once the copper fitting was tight, stability of the inner conducting core was complete. Once centered, the #14 solid conducting wire is inserted in the .625 in. copper tubing until it reaches the desired length. The desired length would be attributed to the length of the ½ in. copper tubing. Our sensor contains a 3 inch #14 solid conducting wire. After inserting the #14 solid conducting wire, we soldered the end to ensure no fluids would begin to leak from our sensor.

Finally, we soldered another #14 solid conducting wire to the side of ½ copper tubing. Thus, giving us a ground for our circuit. This capacitor is shown below in Figure 3.1.1.2.

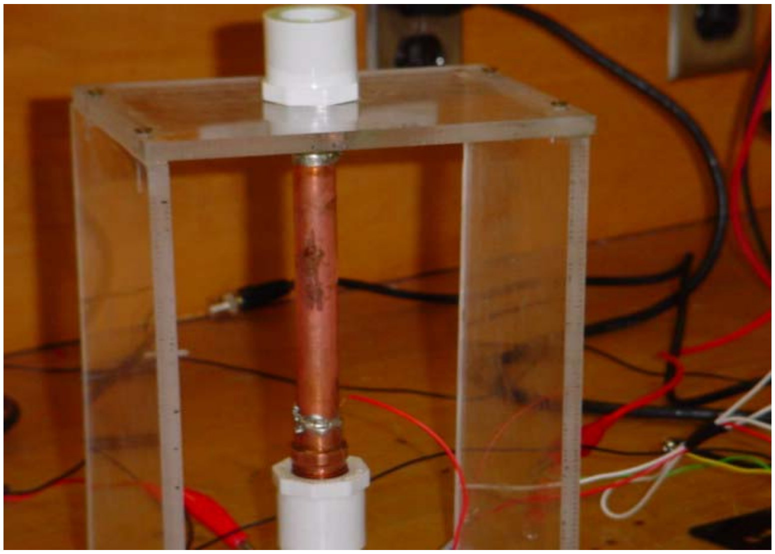


Figure 3.1.1.2 Picture of the Sensor

After construction was complete, the testing phase began. Testing began by using the RC circuit mentioned in Figure 1. We connected a 100 kHz frequency with the amplitude of 2 volts to our sensor in series with a resistance box. This would give us a charging curve to calculate the capacitance of our constructed sensor. In Figure 3.1.1.3 below, it shows you the charging of the capacitor. During each time constant, the capacitor charges 63.2 % of the remaining distance to the maximum voltage level. Our maximum voltage level was measured at 2 volts, thus giving us a 1.26 voltage level. After measuring a 1.26 voltage level, we were able to use a time constant equation. This equation is noted as:
$T=RC$.

Thus, measuring the time from the oscilloscope, and using a resistance box, we were able to solve for the capacitance.

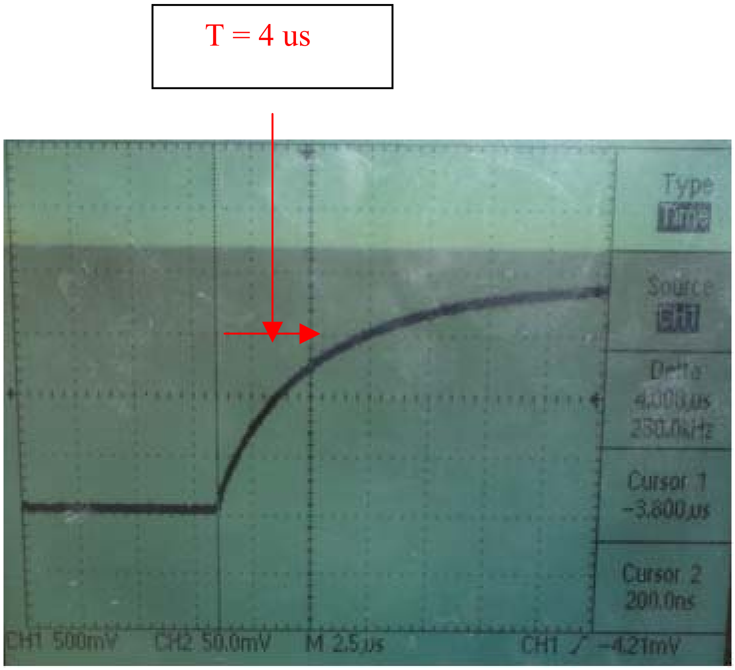


Figure 3.1.1.3 Example of Charging Curve

To ensure consistent values, we were able to simulate the capacitance curve in P-spice. The output should be consistent with that of Figure 3.1.1.3. In Figure 3.1.1.4, you see that the output did match that of the oscilloscope.

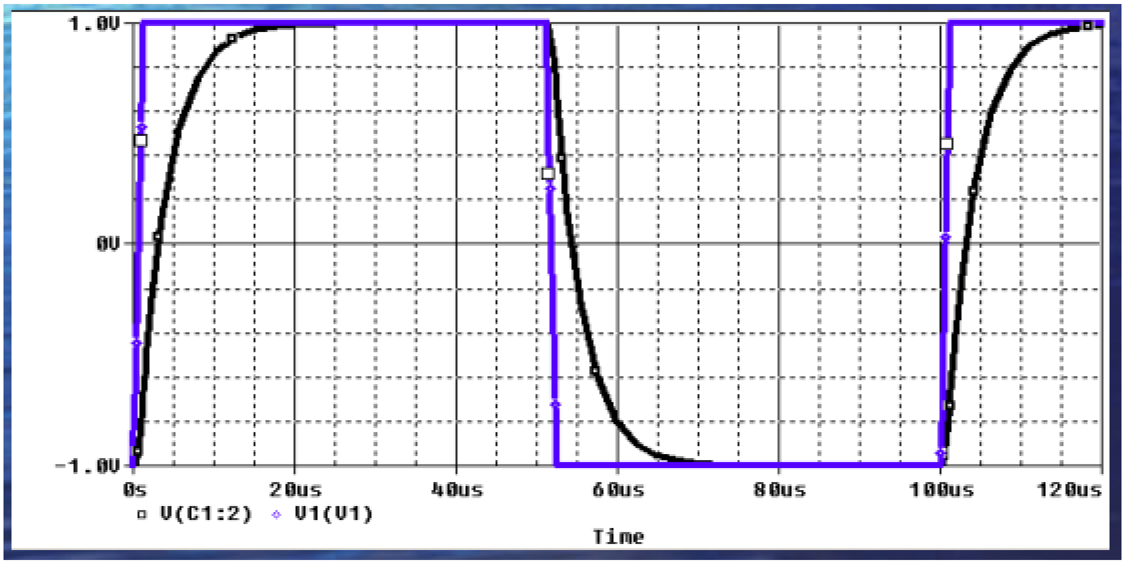
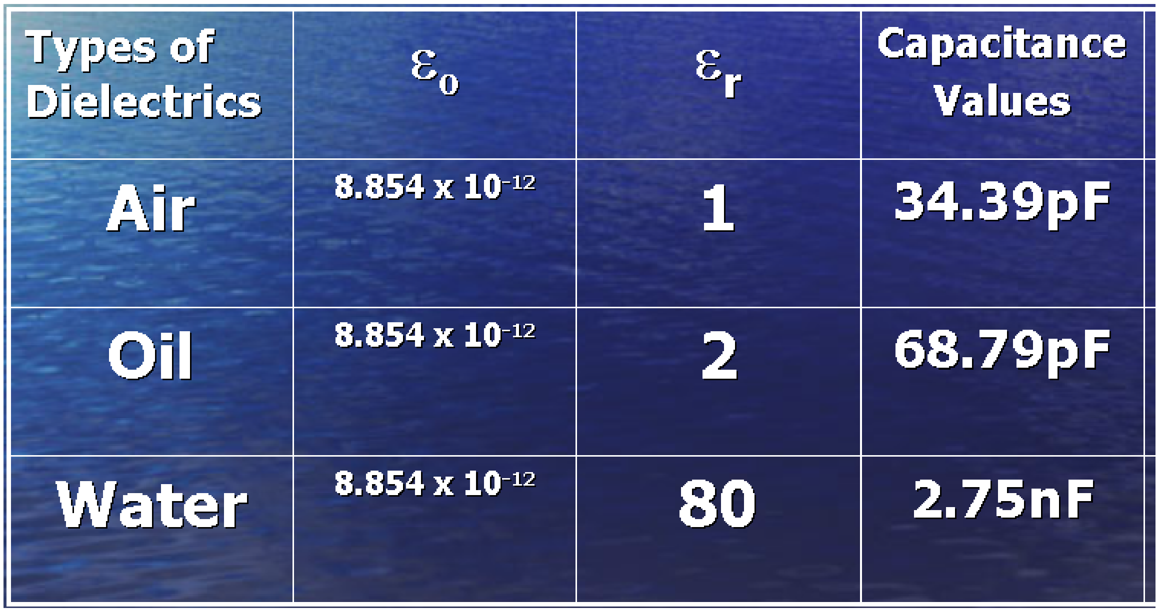


Figure 3.1.1.4

One more way to ensure accuracy would be the theoretical approach. By using the equation 1.1 below, capacitance can also be calculated by knowing the permittivity of free space, permittivity of the dielectric, and also the diameter of the inside and outside conductor. As mentioned before the outside conductor measured .625 inches, while the inside conductor measured .123 inches. Having this information, we were able to calculate the following values in Table 1:



Types of Dielectrics	ε_0	ε_r	Capacitance Values
Air	8.854×10^{-12}	1	34.39pF
Oil	8.854×10^{-12}	2	68.79pF
Water	8.854×10^{-12}	80	2.75nF

Table 3.1.1.5 Theoretical Capacitance Calculations.

Once these values were obtained we were able to compare them. Although the values were slightly different, we were able to justify them due to the internal capacitance of the oscilloscope.

3.1.2. Oscillating Circuit / 555 Timer

Oscillator circuits are essential in almost all system designs. Oscillators provide the system clocks and interface timing that is required by almost all systems. There are mainly two methods to producing a periodic signal, crystal oscillators and RC oscillators, in which our design contains both.

Crystal oscillators are precise and are less prone to environmental distortions such as temperature and noise. Thus, crystal-oscillators are stable and do not require calibration.

RC oscillators cannot offer the same precision or stability as crystal oscillators but are simple to construct and oscillation frequency can be controlled relatively accurately. The fact that RC oscillator circuits are less stable and prone to environmental factors can make them interesting system components. For example, RC oscillators can be manipulated and act as an interface to the user by resulting in variance of the oscillating frequency.

Although high frequency oscillators provide greater resolution, timing constraints and/or chip resources limit the oscillation frequency. Thus it is sometimes desirable to reduce or scale the frequency but maintain the information that the signal contains. The resulting output signal will oscillate at the beat frequency of the two input signals. Such a circuit can also be used as a frequency comparator.

In situations where the frequency of a particular signal needs to be determined, a counter is often used to accumulate the number of oscillations in the sample period. In specific situations where only the incremental change in frequency needs to be determined to extract the information, the above techniques proves valuable in reducing the required data width of the counter.

In implementing the user interface with an oscillator, only the difference in frequency caused by the manipulation of the user needs to be determined. Thus the frequency comparator was implemented to compare the oscillating signal against a signal with a reference frequency. The resulting signal was of much lower frequency and still encoded the relative change in frequency that the user induced. Since a lower frequency signal needed to be processed, the data width of the counter needed in the system was decreased.

The 555 Timer used in the oscillating circuit has applications that include precision timing, pulse generation, sequential timing, time delay generation and pulse width modulation (PWM). These are functions that are essential in the design.

Another desired ability of the 555 Timer is the capability of transforming analogue signals to digital values. By using a 555 chip it is possible to add this desired A/D capability in the circuits with a big resolution, as long as the delay of the A/D conversion is not crucial, as it is the case in most custom circuits. The basic pin connections for the 555 Timer are shown in the figure below.

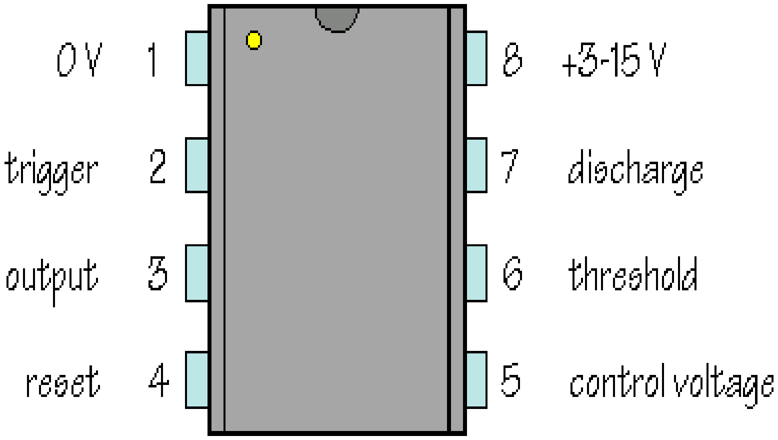


Figure 3.1.2.1 555 Timer

Pin 1 (Ground): The ground pin is the most-negative supply potential of the device, which is normally connected to ground when operated from positive supply voltages.

Pin 2 (Trigger): This pin is the input to the lower comparator and is used to set the latch, which causes the output to go high. Triggering is accomplished by taking the pin from above to below a voltage level of 1/3 V+ (or one-half the voltage appearing at pin 5). The action of the trigger input is level sensitive, allowing slow rate-of-change waveforms, as well as pulses, to be used as trigger sources.

Pin 3 (Output): The output can be returned to a low state by causing the threshold to go from a lower to a higher level, which resets the latch. The output can also be made to go low by taking the reset to a low state near ground.

Pin 4 (Reset): This pin is also used to reset the latch and return the output to a low state. The reset voltage threshold level is 0.7 volts, and a sink current of 0.1mA from this pin is required to reset the device. Delay time from reset to output is typically around 0.5 µS, and the minimum reset pulse width is 0.5 µS.

Pin 5 (Control Voltage): This pin allows direct access to the 2/3 V+ voltage-divider point, the reference level for the upper comparator. It also allows indirect access to the lower comparator, as there is a 2:1 divider to the lower-comparator reference input.

Pin 6 (Threshold): Pin 6 is one input to the upper and is used to reset the latch, which causes the output to go low. The action of the threshold pin is level sensitive, allowing slow rate-of-change waveforms. The voltage range that can safely be applied to the threshold pin is between V+ and ground. A dc current, termed the threshold current, must also flow into this terminal from the external circuit

Pin 7 (Discharge): Usually the timing capacitor is connected between pin 7 and ground and is discharged when the transistor turns "on". The conduction state of this transistor is identical in timing to that of the output stage. It is "on" (low resistance to ground) when the output is low and "off" (high resistance to ground) when the output is high.

Pin 8 (V +): The V+ pin is the positive supply voltage terminal of the 555 timer. Supply-voltage operating range for the 555 is + 4.5 volts to +16 volts, and it is specified for operation between +5 volts and + 15 volts. The device will operate essentially the same over this range of voltages without change in timing period.

In the figure below the basic principle of the PWM circuit is shown. The CPU triggers the 555 (with a negative pulse), this sets the flip-flop, resulting in turning the discharging transistor off. The capacitor Ct is then charged until the voltage on Ct becomes equal to the input voltage V_{in}.

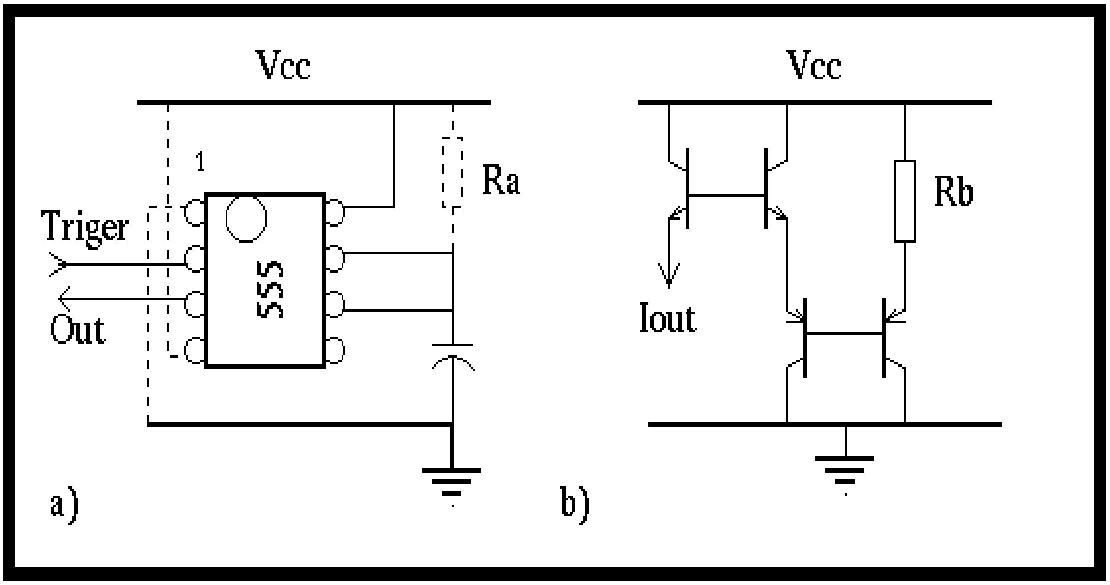


Figure 3.1.2.2 PWM circuit

The voltage on the capacitor is an exponential function in T. It would be desired for the charging to be linear in time, so that the duration of the pulse would be proportional to Vin. The duration of the output pulse is given by the following equation:

$$\mathrm{Vin} = \frac{1}{Ct}\int idt \Leftrightarrow \mathrm{Vin} = \frac{\Delta T}{Ct} \quad (2)$$

The timer in the design is set to count the pulses generated by the oscillator circuit. These pulses are directly correlated to the frequency, which in fact, is the measuring unit for the user to determine the amount of water intake in the lower unit of the boat. In other words, water intake causes the reduction of both the frequency and the pulse count.

After we have successfully found the direct correlation between the pulse counts and the frequency with the amount of water intake, the 555 Timer output is connected to the input of the PIC 16F876. The PIC will then set the threshold levels for the specific counts for the pulses that influence the LED signals to the user.

The design formula for the frequency of the pulses is:

$$f = \frac{1.44}{(R1 + 2R2) * C} \tag{3}$$

* Note that the sensor built for this designed is portrayed by the capacitor labeled C2.

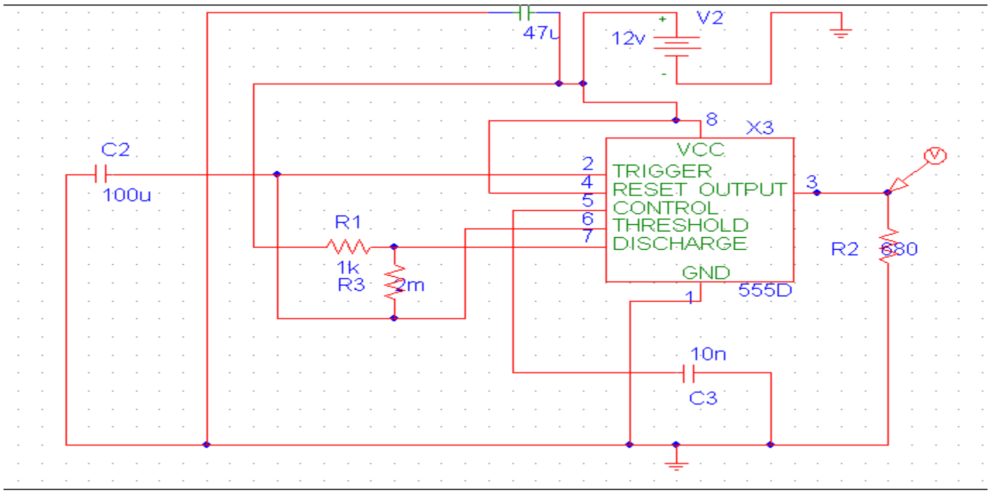


Figure 3.1.2.3 A P-Spice Schematic of the Oscillating Circuit

3.1.3 Microprocessor Board

The microprocessor board is a useful tool for experimentation with microcontroller applications. It acts as the embedded system for the water detector. In general, an embedded system is a special purpose computer device, which is designed to control an operation, given some specific firmware. The microprocessor board is composed of various components, which help compel the design process. The microprocessor contains the circuitry required to operate: 5-volt power supply, 5 volt regulator, 3 LEDs, a potentiometer that acts like a pseudosensor, an RC servo connector and an RS-232 serial port interface. A small prototyping area is included on the microprocessor for the eventual insertion of the oscillator circuit. The microprocessor is versatile and is able to run programs written in assembly, PicC and PicBasic. It also includes in-circuit programming connectors, so the PIC can be reprogrammed with a flash device, and some EPIC Programmer software. All of the PIC I/O pins are joined to a header socket at the bottom edge of the microprocessor board, which allows the oscillator circuit to be connected via the breadboard. All of the pins on the microprocessor board are wired to a 28 pin PIC, which is used to complete the prototype circuitry.

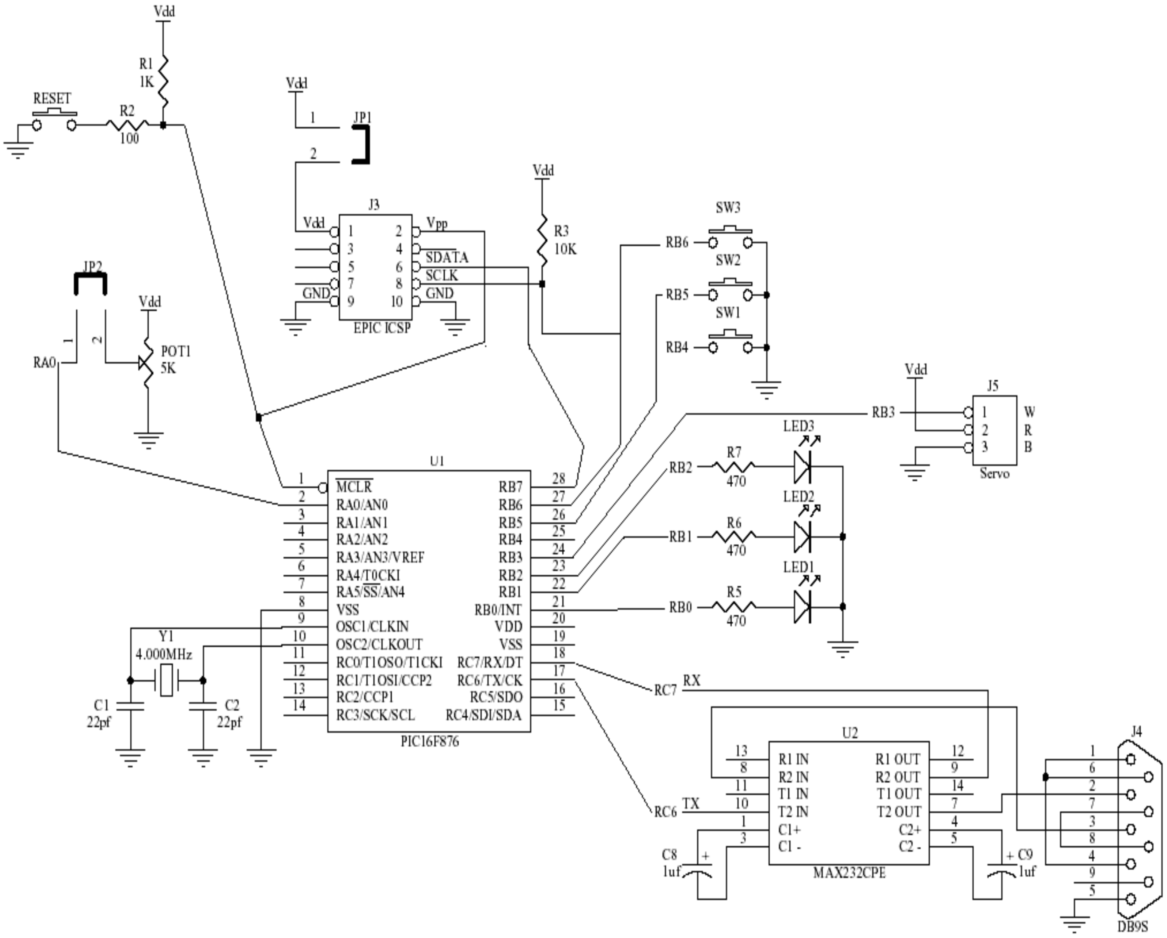


Figure 3.1.3.1

Figure 3.1.3.1 shows a schematic of the microprocessor and its components. The power supply provides regulated +5 volts DC for use by the components. An AC adapter helps to ensure that the recommended DC voltage of 7.5 to 16 volts is provided to the board via the DC power connector (J2). The three programmable LEDs are connected to ports RB0-RB2. There is also 1 power LED that is always on when power is applied to the microprocessor. Resistors R4 - R7 are the current limit series resistors for the LEDs. Three push button switches are connected to pins port RB4 - RB6 on the PIC. A closed switch will show a 0 and an open switch will show a 1. These schematics can be seen below in figure 3.1.3.2

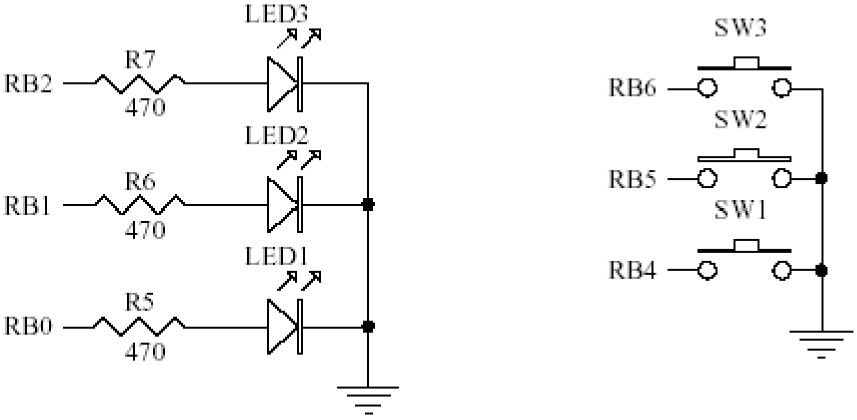


Figure 3.1.3.2

The microprocessor board includes a potentiometer connected to port RA0 of the PIC. Jumper JP2 allows the potentiometer to be disconnected from the PIC pin when the pin is used for other purposes. The potentiometer may also be used as a switch by setting the input pin to digital mode and moving the pot wheel all the way to either the 5-volt or ground position, which ultimately provides either a high or low on the input. The three-pin header (J5), shown in figure 3.1.3.3 is used to connect the RC servo to the microprocessor board. Pin 1 is the servo pulse input, which is connected to port RB3. Pin 2 is the 5 volts coming from the source to the servo, and Pin 3 is the ground. Most RC servos are operated by sending a 1ms to 2ms pulse 50 to 60 times a second. The pulse width determines the servo position.

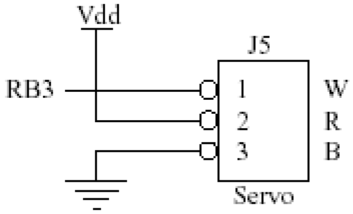


Figure 3.1.3.3

The microprocessor includes an RS232 interface to connector DB9S female right angle connector (J4) shown below in figure 3.1.3.4. This allows asynchronous serial communication with other devices, including PCs. A MAX232 IC in socket U2, along with several capacitors, generates the required RS232 voltages. The serial TX line (pin 2 on J4) is connected to port RC6 through the MAX232. The serial RX line (pin 3 on J4) is connected to port RC7 through the MAX232. RTS is connected to CTS (pin 7 to pin 8) on J4. DTR is connected to DCD and DSR (pin 1 to 4 to 6) on J4. These jumped connections make most common programs think the microprocessor board is online and ready to communicate.

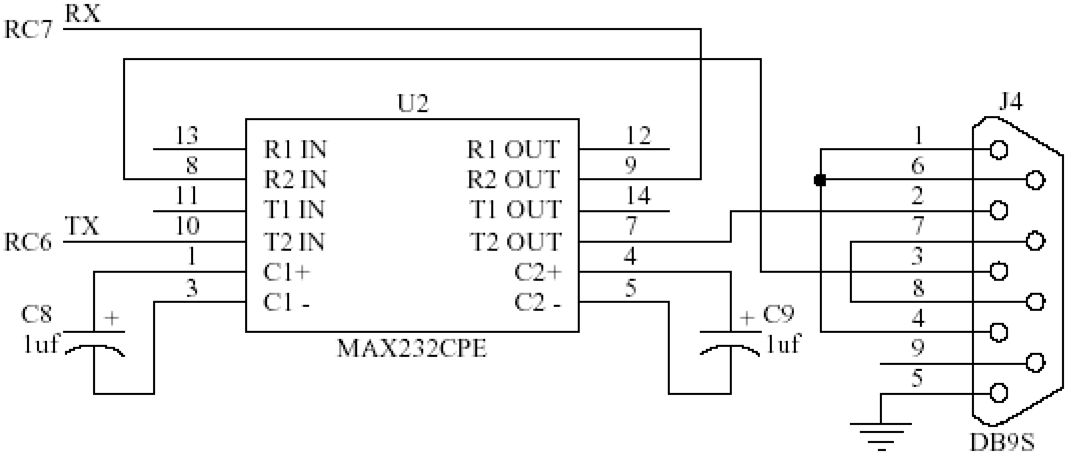


Figure 3.1.3.4

The microcontroller board utilizes a high-performance FLASH PIC16F876 shown below in figure 3.1.3.5, which provides the design team with the highest design flexibility possible. It has the capability to be programmed and erased in blocks rather than bytes by using the EPIC Programmer software. This PIC has 8096x14 words of FLASH programmable memory as well as 256 data memory bytes, and 368 bytes of user RAM. It features an integrated 5-channel 10-bit Analog-to-Digital converter, which converts analog input voltage to a ratio metric digital equivalent value, and it also consist of 22 I/O pins. Peripherals include two 8-bit timers, one 16-bit timer, a Watchdog timer, and a Brown-Out-Reset (BOR), which will force the device to the RESET state if the power supply voltage falls below the specified voltage level. This PIC also allows for in circuit-serial programming to occur as opposed to creating an external circuit much like other devices. The Universal Asynchronous Receiver Transmitter (UART) is a module that can operate as a full duplex asynchronous communications port. By operating in the asynchronous mode, the UART can be interfaced to the PC serial port for multi-drop data acquisition applications, and I2C or SPI communications capability for peripheral expansion.

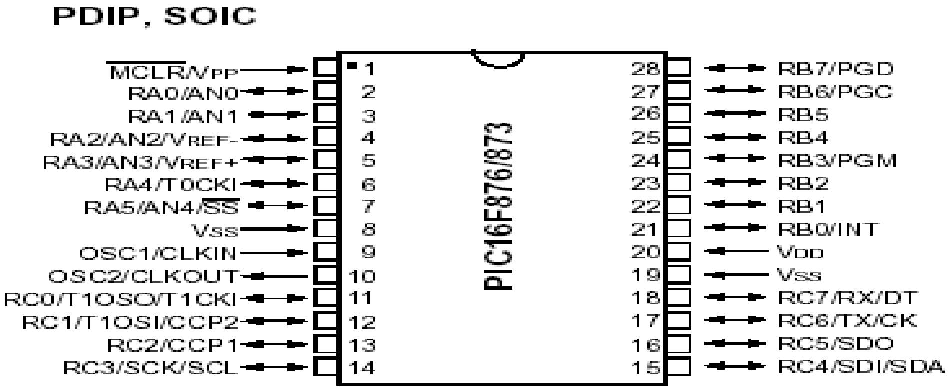


Figure 3.1.3.5

Precision timing interfaces are accommodated through two CCP modules**,** that can be configured to operate as an input capture, or a timer compare. An in-circuit debugging feature allows the designer to “emulate” the PIC16F876 device without an in-circuit emulator since the microprocessor board itself acts like an emulator. The various applications of the PIC16F876 range from body controllers, programmable machine controls, network maintenance, and diverse sensory conditions. In the case of the water detector, we recognized the functionality of the microprocessor board. We also recognized the opportunity the board would provide for parallel development of the firmware and the sensor, as well as avoid having to “reinvent the wheel”. Ultimately, this board increased productivity and helped make the design team more efficient as we work toward building a successful prototype.

3.2. Software Approach

The main portion of the software involved in the water detection system deals with the counting of pulses of the function that is generated by the oscillator circuit. Code will be written for the PIC16F876 that will enable one of its input pins to take in the output of the oscillator circuit and count each time it reads a change in the signal. One-way to do this is to count the number of interrupts that occur at the desired input pin. Once the pulses are counted we will be able to set threshold values. If the number of pulses counted is below a certain limit, code will be written to turn on one of the LEDs to warn the boat occupant that water has been detected in the lower unit.

There will be a minimum amount of user interaction with the actual system. The only interaction that will actually take place will be when a warning led is turned on letting the user know that water has been detected in the lower unit.

3.2.1 PIN Selection

We selected to use pin RB4 as the input for the systems interaction with the oscillator circuit. This pin was arbitrarily selected and can be changed if it is deemed necessary. The location of RB4 is denoted in Figure 3.1.3.5.

Whenever there is a transition from high to low, or low to high on pin RB4, the program counts an interrupt, and this is count results in the pulse count of our system.

Therefore, counting the pulses generated by the system over a set period of time, we will be able to denote a difference when water has been mixed with the oil. Once the capacitance of the structure goes up due to the presence of water, the overall frequency of the function generated by the oscillator circuit goes down.

Therefore, counting the pulses generated by the system over a set period of time, we will be able to tell if there has been a change in the overall frequency of the system. Figure 3.2.2.1 shows the flow diagram for the software that will be needed to count the pulse generated by the oscillator circuit.

The first constraint here will to be to make sure that all counting is done at the same length of time. One way to do this would be to set a timer. Code will be written that will have one of the LEDs of the micro controller board turn on for about 1 second. Each time the LED is on, the system is allowed to count the interrupts that occur at pin B4. Once the LED goes off, the counting stops, the value is printed to the screen, and the pulse count is cleared.

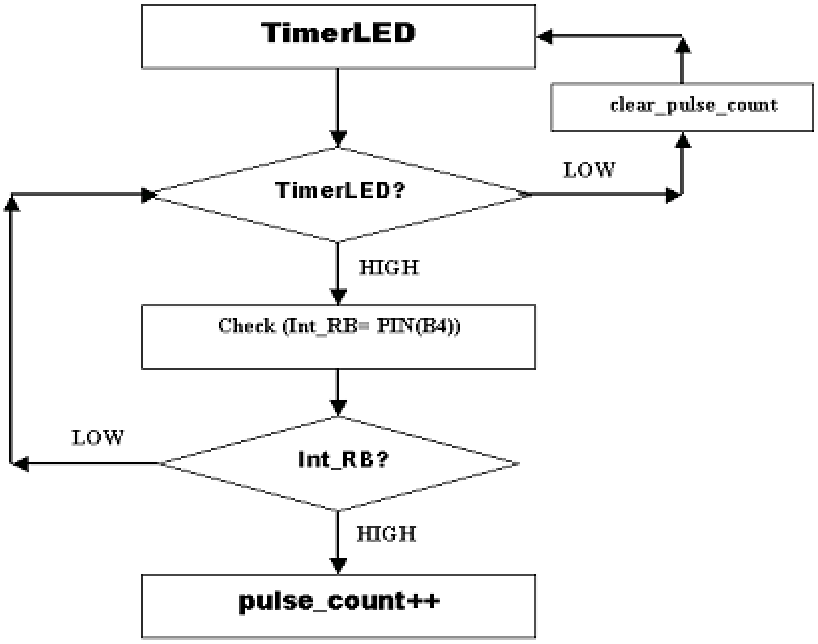


Figure 3.2.2.1 The Flow Diagram for the Pulse Counting.

3.2.3 Threshold Frequency Flow Diagram

Once a pulse count is collected by the PIC, and before it is cleared, the value will be compared to threshold values that will be set by the programmer. These threshold values will correspond to frequencies and pulse counts of mixtures of oil that are deemed to be detrimental to the well being of the lower unit.

Since the frequency of our system falls when there are higher amounts of water present in the oil, our system will check if the counted pulses has fallen below the threshold limit. If the value has fallen below the threshold, then a LED will be turned on. This LED will warn the occupant that there is water present in the oil. Furthermore, if the pulse count falls below the next threshold, another LED will be activated and an alarm will sound. The flow diagram for these comparisons is shown by Figure 3.2.3.1.

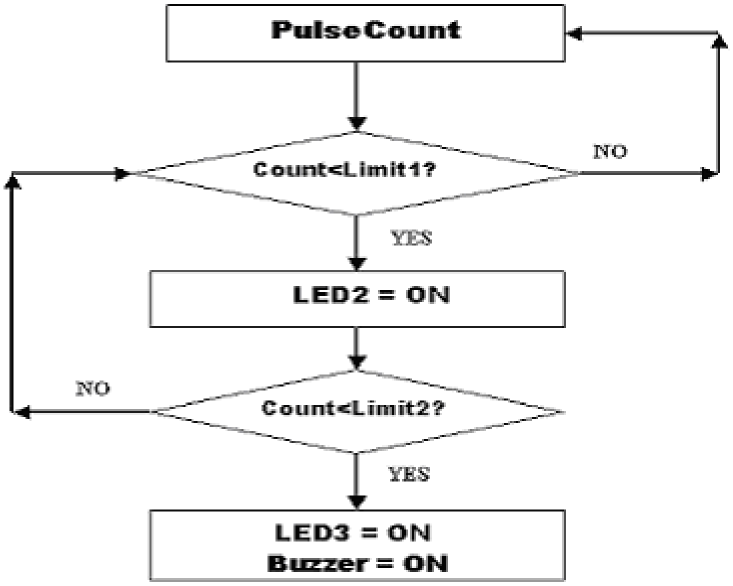


Figure 3.2.3.1 The Flow Diagram for Pulse Count Compare.

4. TEST SPECIFICATIONS

In order to acquire accurate results for our design, there were a few very important design constraints to be aware of. The table below illustrates the constraints and the instruments required to overcome them in order to obtain consistent results in our data.

Requirements	**Pspice**	**Digital Multimeter**	**Oscilloscope**	**Performance Testing**
Input Voltage	●	●		●
Capacitance	●	●		●
Frequency	●	●		●
Output Latency	●			●
Endurance				●
Circuit Board	●	●	●	●
Sensor Design		●	●	●

Table 4.1 Constraints vs Instruments

4.1 P-Spice

In the process of building the prototype, it is important to recognize and regulate the different levels of voltage associated with our system. PSpice was used to help simulate our circuit design. PSpice helped us to simulate particular charging curves that have been tested by using the oscilloscope. This was done by simulating a simple RC Circuit with a constant resistance and a capacitance value that varies depending on the capacitance measured, which corresponds to the capacitance sensor.

4.2 Digital Multi-meter

The digital multi-meter will allow for the measurement of the frequency response generated by the oscillator circuit design. The meter will be connected to the output of the 555 timer to determine the frequency that corresponds with the capacitance of the capacitance sensor. The meter will also be used to measure the voltage that is supplied as the power of the circuit. With inconsistency in the voltage level due to the alternator, safety becomes a concern. We will also use a digital multi-meter to ensure a consistent supply of voltage between 12-15 volts supplied by the boat battery. By regulating this voltage using the digital multi-meter, we are reducing the risks of any kind of shortage in the system.

4.3 Oscilloscope and Function Generator

After checking the characteristics of a capacitance meter it was established that the meter calculates capacitances by performing an analysis of the charging curve of the capacitor. The meter applies a voltage to a resistance value and causes the capacitor that is placed in the meter to charge. It was determined that the same analysis done by the capacitance meter could be performed by connecting a simple resistor-capacitor circuit (RC circuit), using the capacitance sensor as the capacitor of the circuit. Figure 2 shows an example of an RC circuit.

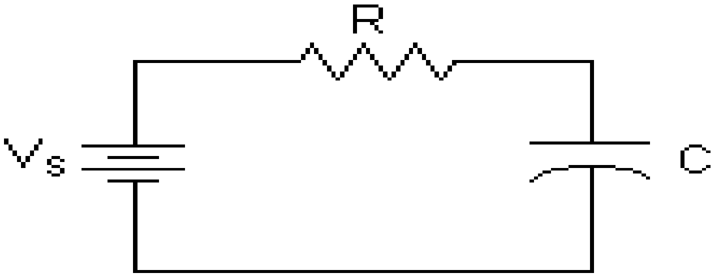


Figure 4.3.1 Simple RC Circuit

In the analysis without the meter, the voltage source Vs, will be replaced by a function generator. Additionally, the resistance, R, will be replaced by a decade resistance box.
The function generator will be set to generate a square wave at 10KHz or 100KHz with amplitude of 2 Volts. The positive led from the function generator will be connected directly to the positive side of the resistance box. Then, the negative end of the resistance box will be connected to the positive end of the capacitance sensor. To complete the circuit, the negative ends of both the sensor and the function generator will be connected.

Once the generated wave from the function generator travels through the resistance box and to the capacitor, the capacitor will charge and produce a charging curve. Since the amplitude of the function generator will be set to 2 Volts, the capacitor will charge until it reaches the maximum voltage of 2 Volts. An example of a charging curve is denoted by Figure 4.3.2.

The 100% mark on the y-axis shows the maximum voltage that the capacitor can reach. The x-axis in Figure 3 consists of the time constants. During each time constant, the capacitor charges 63.2% of the remaining distance to the maximum voltage level. To allow for the viewing of the charging curve, an oscilloscope will be connected in parallel with the capacitance sensor. The oscilloscope will also be helpful in finding the value of the first time constant.

Once the first time constant (T) is found, the equation T = RC can be used to determine the capacitance of the sensor. The value of the resistance from the resistance box used in the RC circuit will be known. Therefore, the capacitance of the capacitance can be calculated by dividing the first time constant by the resistance value, T/R.

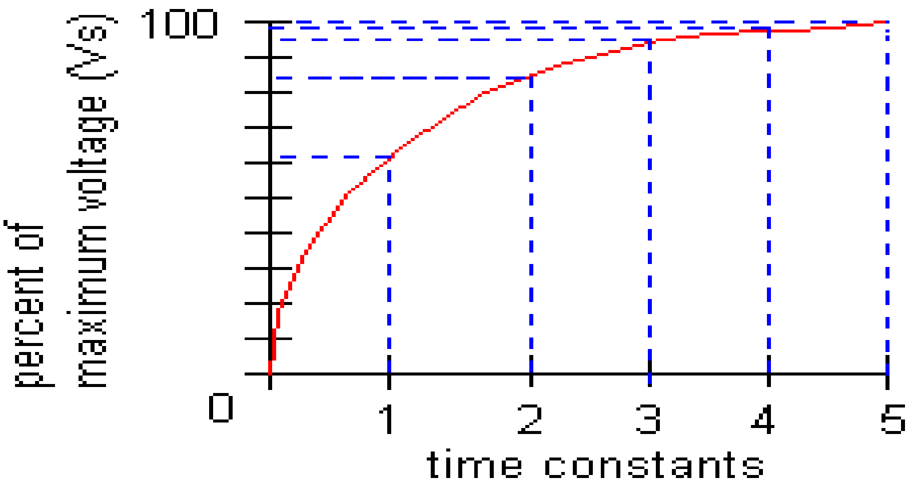


Figure 4.3.2 Capacitor Charging Curve

4.4 Circuit Board

This circuit board will include our microprocessor and oscillating circuit. Multiple testing of the circuit board will consist of the individual electronic components wrapped with wire to ensure accuracy. By wire wrapping our design we will be able to examine all potential design flaws. The software Orcad will be used to draw the circuit schematic. This schematic will also aid us in the completion of the wire wrapped board.

Since our board will be newly wired, the old test data that we had obtained before will be invalid. Using the new circuit board, we will, once again, manually add water to an oil mixture to find new measurements for the capacitance and the frequency obtained by the digital multi-meter. Since the microprocessor chip will be wired to the circuit board, we will be able to output the information to the LED’s designed to alert the users of water contamination.

4.5 Sensor Design

The sensor will be designed to fit the inside of the lower unit of the engine. The original design was to screw the sensor in the side of the lower unit, but after careful examination it was decided to mount our new sensor inside the lower unit. In order to make this feasible, we had to reduce our size of the sensor from ½ inch copper tubing and 7 inches length to 3/8 inch copper tubing with 3 inches length.

Our testing procedure will measure the consistency of the capacitance due to multiple trial measurements compared to the same values found with the original prototype. These values should be slightly different due to the smaller diameter of the copper tubing and a new circuit board.

4.6 Performance Testing

Performance testing will be made throughout different stages of the design in order to guarantee the reliability and endurance of our product. The performance testing will include durability and accuracy of data received from the circuit board and the sensor during the operation of the marine craft.

We anticipate that the frequency and capacitance data received will fluctuate slightly due to temperature, humidity, and location.

Using the exact same testing procedures, our product will also be tested to verify any differences on data between salt water and regular water

5 Test Certification

This section of our document discusses testing techniques used to verify data and results of our device.

5.1 Capacitance Sensor

The first objective of this project was to decide how to detect water in the lower unit of a marine outboard. Measuring the conductivity of the oil/water content was an option. By using a calibrated conductivity meter furnished by the Chemical engineering department here at MSU, we took measurements ranging from 5% to 80%. As you will note below the measurements were highly unstable. To establish consistent measurements, we took several samples and averaged our results on two different occasions. The results are listed below in Figure 5.1.1.

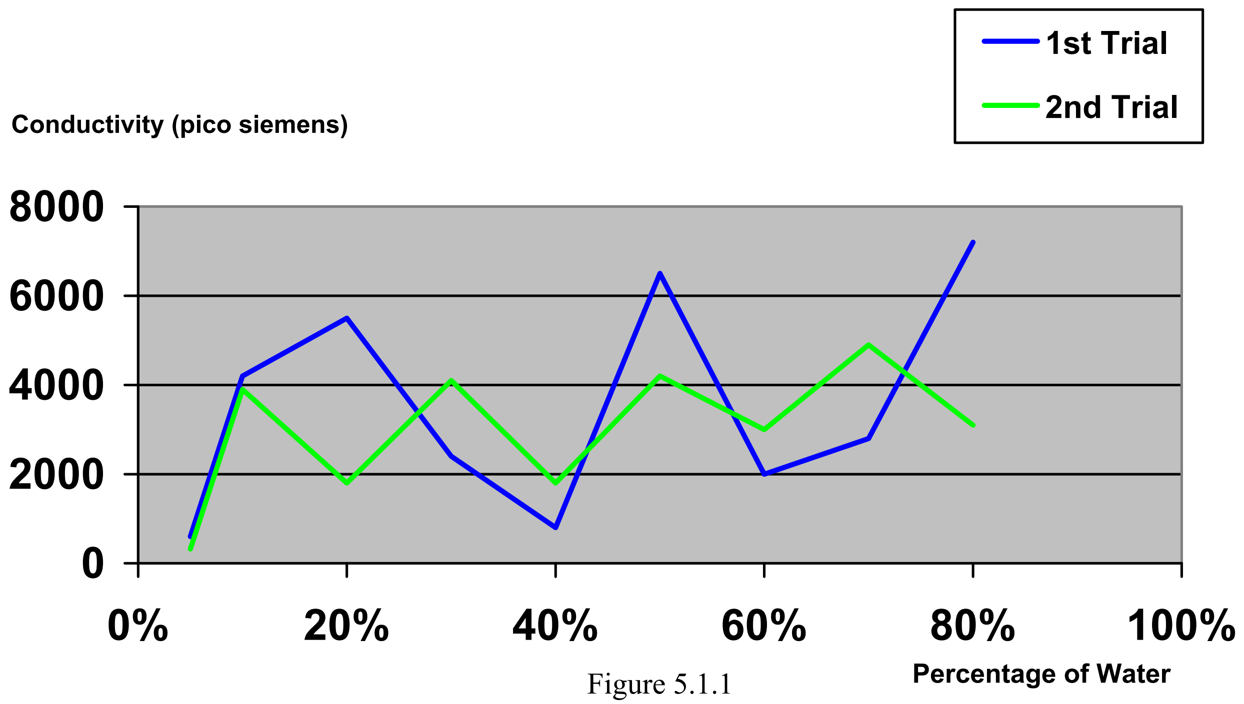


Figure 5.1.1

The results, and further investigation helped us to conclude that the conductivity measurements would not be reliable due to its sporadic behavior, therefore a different approach had to be taken.

After extensive in depth research, we found that capacitance could be used to measure the change in frequency between oil and water on a consistent basis. Now our main objective was to build a sensor and verify that it was consistent with any other comparable capacitors as far as charging times goes. In order build a capacitance sensor we had to first understand, how a capacitance sensor worked. It was established that the capacitance meter in the lab calculates capacitances by performing an analysis of the charging curve of the capacitor. The meter applies a voltage to a resistance value and causes the capacitor that is placed in the meter to charge.

It was determined that the same analysis done by the capacitance meter could be performed by connecting a simple resistor-capacitor circuit (RC circuit), using the capacitor in question as the capacitor of the circuit. Figure 5.1.2 shows an example of an RC circuit.

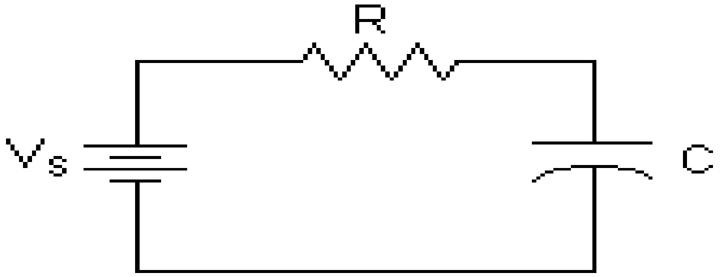


Figure 5.1.2. Simple RC Circuit

In the analysis without the meter, the voltage source, Vs, will be replaced by a function generator, and a Decade resistance box will replace the resistance, R.

The function generator will be set to generate a square wave at 10KHz with amplitude of 2 Volts. The positive led from the function generator will be connected directly to the positive side of the resistance box. Then, the negative end of the resistance box will be connected to the positive end of the capacitor. To complete the circuit, the negative ends of both the capacitor and the function generator will be connected.

Once the generated wave from the function generator travels through the resistance box to the capacitor, the capacitor will charge and produce a charging curve. Since the amplitude of the function generator will be set to 2 Volts, the capacitor will charge until it reaches the maximum voltage of 2 Volts. An example of a charging curve is denoted by Figure 5.1.3.

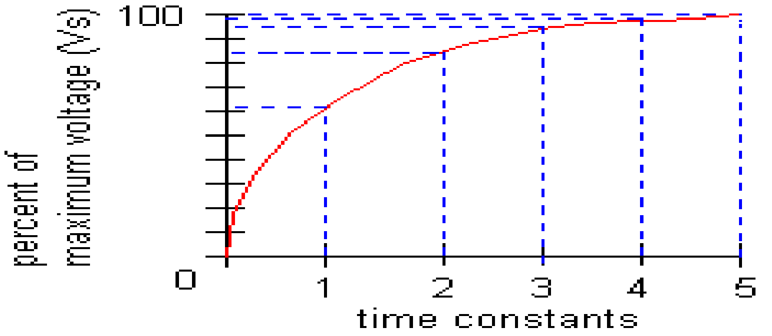


Figure 5.1.3

The 100% mark on the y-axis shows the maximum voltage that the capacitor can reach. The x-axis in Figure 3 consists of the time constants. During each time constant, the capacitor charges 63.2% of the remaining distance to the maximum voltage level.

To allow for the viewing of the charging curve, an oscilloscope will be connected in parallel with the capacitor. The oscilloscope will also be helpful in finding the value of the first time constant.

Once the first time constant (T) is found, the equation T = RC can be used to determine the capacitance of the capacitor. The value of the resistance from the resistance box used in the RC circuit will be known. Therefore, the capacitance of the capacitor can be calculated by dividing the first time constant by the resistance value, T/R.

This process proved to be a very effective way to determine the capacitance of our capacitor. The simplest way to test our theory was to simulate our exact RC circuit in P-spice.

After an initial analysis of the capacitance sensor, we were able to obtain that the capacitance our sensor was about 20pF, however, combined in parallel with the oscilloscope, the capacitance was about 120pF. Therefore, we took a snapshot of the charging curve that was generated from the sensor and the oscilloscope and compared it to the charging curve that was simulated in PSPICE. Figure 5.1.4 denotes the circuit that was used in PSPICE and Figure 5.1.5 denotes the curve generated in PSPICE. Additionally Figure 5.1.6 shows the snapshot of the charging curve from the sensor and the oscilloscope.

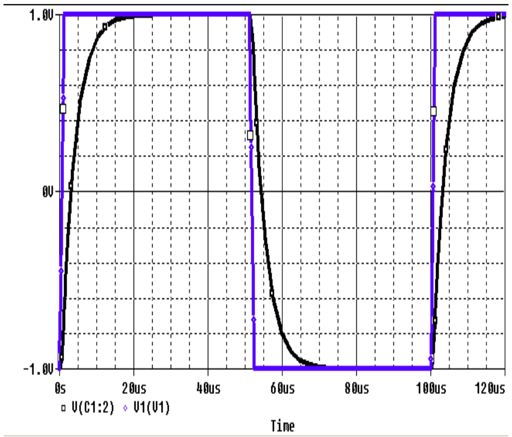


Figure 5.1.5 PSpice Charging Curve

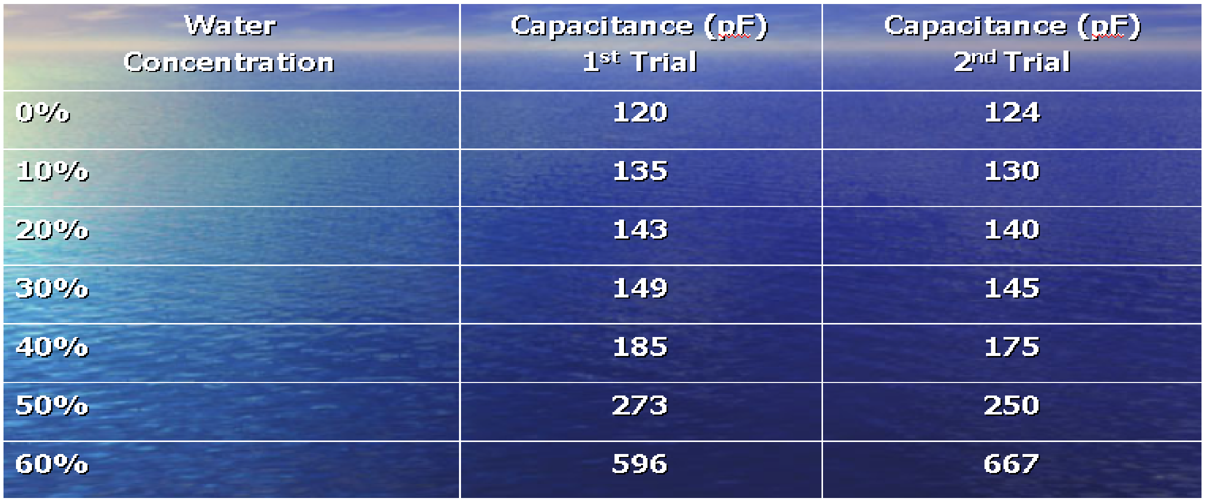
Figure 5.1.6 Charging Curve

The curves turned out to be very similar; therefore we were certain that the capacitance we derived by doing an analysis of the charging curve was correct. This allowed us to move on to the next stage of testing.

The picture in figure 5.1.7 denotes a pseudo lower unit with an installed capacitance sensor. This pseudo lower unit is a stainless steel cup combined with a blinder to act as a drive shaft rotating within the stainless steel cup. This stainless steel cup was filled with lower unit oil, and the capacitance was measured with varying concentrations of water and oil. The blender has a solid shaft with a plastic gear mounted on the end, which turns to simulate moving gears in the lower unit of an outboard motor. The sensor has two slits and several small holes that are drilled at random to allow the mixture to flow through the sensor. A hole was drilled into the metal cup and a rubber seal was placed in the hole to prevent the sensor from shorting out. The sensor was then inserted in the stainless steel cup and epoxy was applied to create a seal. A solid conductor wire was soldered to the inside electrode, while the ground was soldered to the outer shell of the sensor. These wires were then place in the weatherproof box labeled C+, and C-. C+ is defined as the solid conductor electrode while the C- is defined as the ground of the outer shell of the sensor.

Figure 5.1.7

The next big approach consisted of capacitance measurements. This measurement would be taking in the same manner as before. Several trial samples would be conducted with varying percentages of oil and water. After taking these measurements, we noticed very consistent values at different percentages of water. These results can be seen in the table below.



Water Concentration	Capacitance (pF) 1st Trial	Capacitance (pF) 2nd Trial
0%	120	124
10%	135	130
20%	143	140
30%	149	145
40%	185	175
50%	273	250
60%	596	667

Figure 5.1.8

After noticing these consistent values, we begin integrating our sensor into our oscillating board and measured the frequency. These values seem to be inversely proportional. As the capacitance increased, the frequency decreased. This is shown in the graph below.

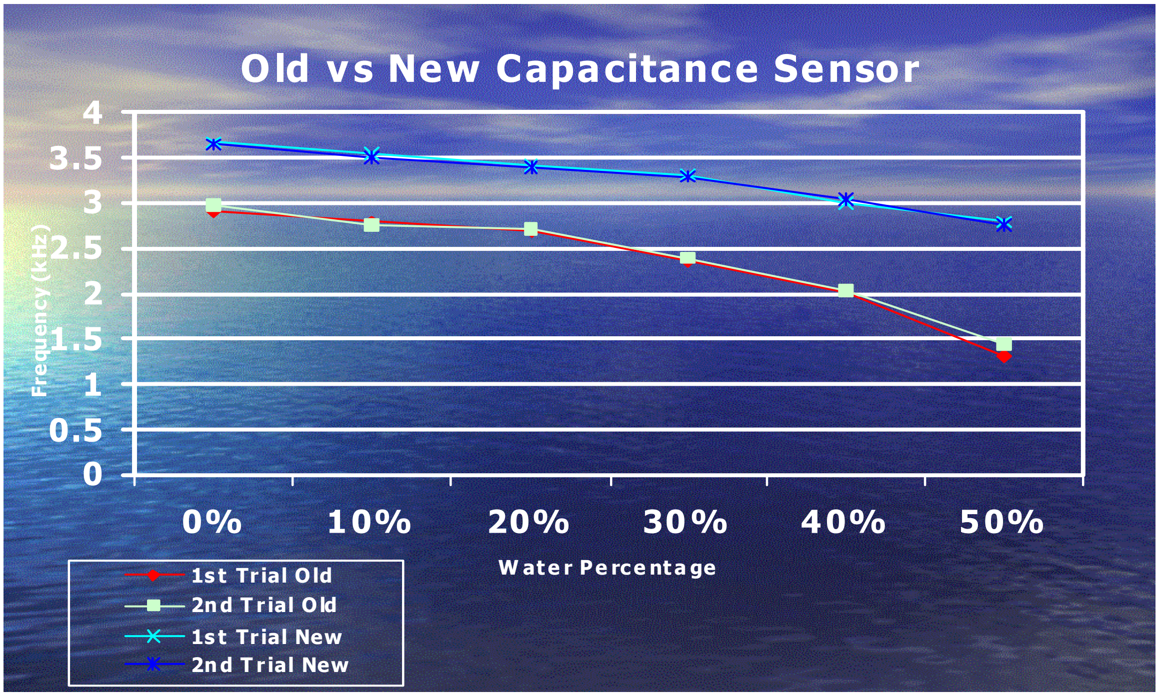


Figure 5.1.9

5.2 Circuit Board

The first P-spice simulation used in our test certification was the oscillating circuit. This process was used to simulate a pseudo-AC voltage with pulses. The objective was to create a frequency up to 5K. This frequency level would allow use to count the pulses generated by our oscillating circuit. The frequency was measured with a digital multi-meter. After successfully defining this objective, our next step was to integrate the oscillating circuit with the microprocessor. In order to integrate these two systems, many issues had to be answered. One issue with the oscillating circuit dealt with the noise level of the output of the oscillating circuit. A Schmidt trigger was added to our design to clean up the signal of our oscillating circuit. This addition enabled a clear signal to be transferred into the PIC16877 processor.

All marine outboards operate on a 12-volt source. To ensure a 12-volt source, a digital multimeter was used on the printed circuit board. The output of our circuit board was also measured with the multimeter. This measured in the 5-volt output range.

The final circuit board was tested regularly with the software. This software would count the pulses of the oscillating circuit and display it to the screen. At this point, the sensor would be submerged in different concentrations of water and oil mixture.

Another verification used in the design approach was comparing the Orcad layout to the actual board. This verification depends on the accuracy of the finished product. After soldering all the electronic components, the output of the Schmidt was not producing a signal to our sound indicator. Once the schematic was compared to the circuit board, a ground was found to be missing from the schematic. The digital multimeter was used to find this error

The annunciation panel as seen below in Figure 5.2.1 and Figure 5.2.2 is designed to alert the user of a potential problem. The panel has a low, medium and high-level alert light emitting diode status. Notice in Figure 5.2.2, that the leds are programmed to alert the user as soon as the water concentration begins to reach different levels. The first led is set at 4800 pulse interrupts. As the interrupt count exceeds 4800, the first led will light. As soon as the interrupt count exceeds 5000, then the medium led will be displayed. Notice that the low led remains on until the interrupt falls below 4800. This statement holds true for all the leds. Once the interrupt count exceeds 5200, the high-level alert will be set. Once the high-level led is set, a 40dB alarm is set as well. This alarm will continue to warn the user until the reset button in depressed.

The deployment of the buzzer indicates a high level of water concentration in your lower unit, thus warning the boat occupant of thermal damage to the lower unit. The boat occupant should immediately shut down the outboard engine. The annunciation panel, which is wired to the microprocessor, was tested with the circuit board. The microprocessor interpolates the pulse count and transmits the data to the annunciation panel, which in turn is programmed to light up given various amounts of water or pulse counts. As mentioned earlier, the output of the Schmidt trigger was not grounded, therefore it gave us problems with the annunciation panel as well.

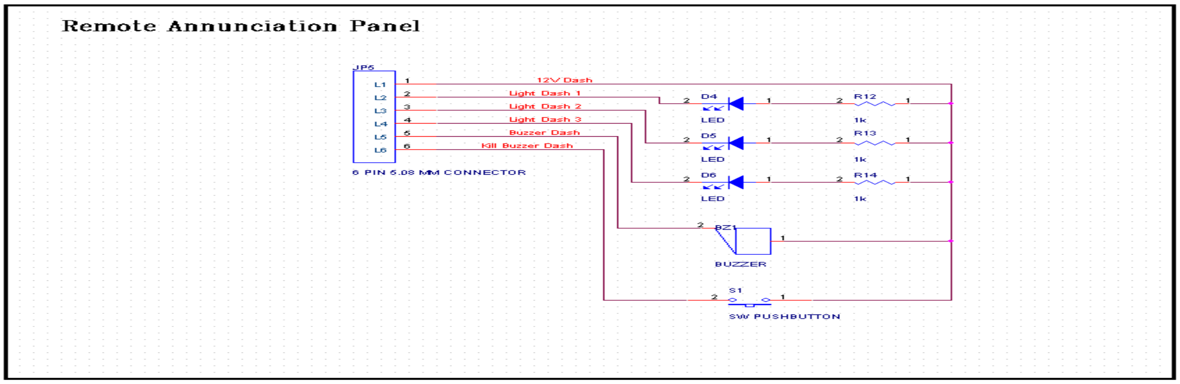


Figure 5.2.1

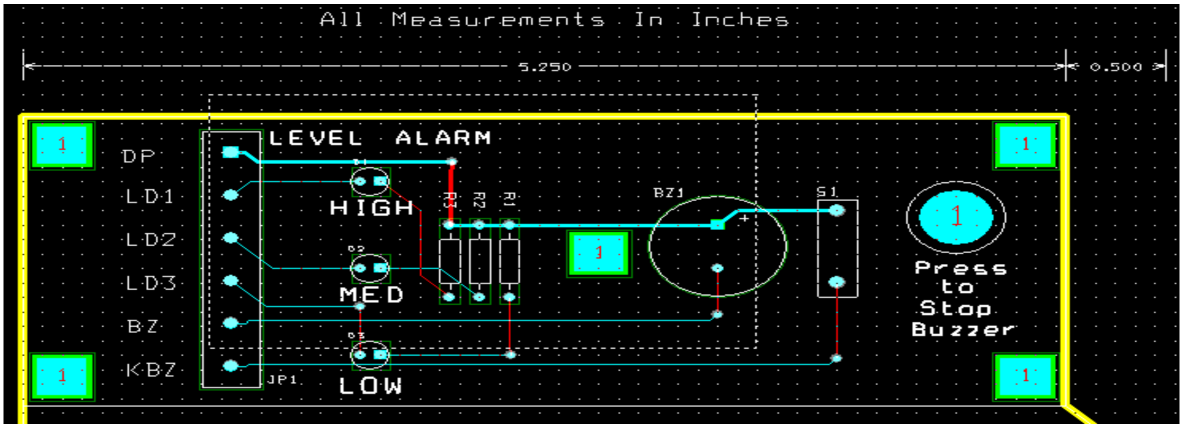


Figure 5.2.2

This circuit board will include our microprocessor and oscillating circuit. Multiple testing of the circuit board will consist of the individual electronic components wrapped with wire to ensure accuracy. By wire wrapping our design we will be able to examine all potential design flaws. The software Orcad will be used to draw the circuit schematic.

The circuit board layout has some modifications that vary from our original design of an oscillating circuit with a microprocessor. One main objective consisted of our layout being mounted within our weatherproof box. Once the dimensions were established, the circuit board could be built to those standards. This figure is shown below.

The quarters in Figure 5.2.3 are present for size comparisons. The annunciation panel was scored and broke off the original circuit board so that it could be mounted on the center console of the boat. After detaching the annunciation panel, the circuit board could be placed in the weatherproof box that had been selected for durability purposes.

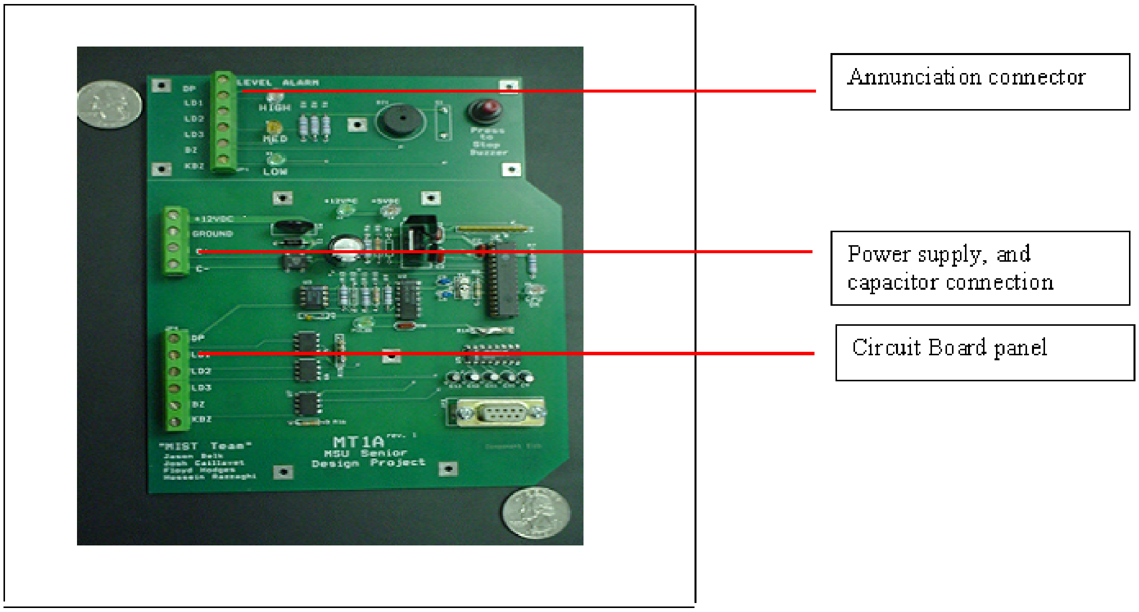


Figure 5.2.3

The annunciation panel was wired to the circuit board panel. The six labels on the annunciation matched the labels on the circuit board. The first position was labeled DP. DP referred to the display power. This position on the circuit board powered the annunciations panel. The second position was labeled LD1. LD1 referred to the first led. The third position was labeled LD2. LD2 referred to the second led. The fourth position was labeled LD3. This label referred to the third led. The fifth position was labeled BZ. BZ referred to the buzzer. Finally, the sixth position was labeled KBZ. KBZ referred to killing the buzzer. These connections enabled our team to control all the components through our Pic processor.

The wiring harness was made of conduit connectors and flex conduit. Using the flex conduit gave this project the flexibility to be mounted at various locations. Due to the different style of boats, this was an important factor to take into consideration. The importance of the conduit connectors instills the weatherproof condition of the wiring harness. This feature is very important in a corrosive atmosphere of the water environment. The locations of the power supply (12-volt battery) and capacitor connection (sensor) are also shown in figure 4. All the hardwiring on this project would be connected through the flexible conduit.

5.3 Oscilloscope

The oscilloscope was used to verify the frequency, and calculate the capacitance of the sensor. These measurements would change due to the amount of dielectric in the capacitor. The dielectric is directly associated with the ratio of oil to water.

5.4 Performance Testing

This testing was done at the Mississippi State University chemical engineering laboratory. All oil testing was done with highly accurate measuring devices that were calibrated in November. These test were also done several times for accuracy purposes. All oil samples were measured and mixed according to their weight. For example, 10% water had 27 grams of oil and 3 grams of water. According to Dr. Hossein Toghiani, a MSU professor, this is the most accurate way to measure percentages.

6 Conclusion

Our team met a huge challenge in determining a feasible approach in determining water contamination in the lower unit. Initial options included building sensors that measured:

- Conductance/Resistance
- Optical
- Absorption

After spending a large portion of the year trying to figure out methods of measuring the conductance and resistance of oil with different water mixtures, we finally concluded that there was no definite trend in the values with increasing water concentration.

Since so much of the year was taken up by erroneous results due to the persistence of trying to get the conductance or resistance sensor to work, we quickly fumbled through some other options.

We came across the idea of designing an optical sensor that actually detected the change in color of the oil as water concentration increased. Even though the oil actually did turn into a milky white color with the addition of water, the change was not drastic enough for us to be able to measure the water intake accurately.

Next, we came upon the idea of absorption. A general overview of this method dealt with actually heating the oil to figure the energy transmitted. This was quickly overturned once expense and difficulty were evaluated.

Finally we came upon measuring the capacitance. Our sensor received consistent measurements after multiple testing of the oil with different water percentages. The oil went through testing from water percentages ranging from 10% - 70%. We even tested pure oil and saw the capacitance change as water was manually inserted into the oil.

Due to the use of an oscillating circuit, our design was also set to measure the frequency and the pulse count of the oil. This actually proved to be the determining factor of water detection in the oil. We quickly realized that pure oil has a set frequency of about 2.9 kHz and with an increase in water; both the frequency and the pulse count steadily decrease.

Upon the completion of this term, we have been able to finish a design of a packaged version of our overall design. This includes a PCB board that contains both the oscillator circuit and the Micro-Controller. This board also includes a display panel to allow for the warning of the boat occupant when water has been detected in the lower unit chamber, as well. Additionally, a RS232 interface was added to the PCB to allow for the analysis of the pulse counts that were being generated by the Microcontroller.

7. ACKNOWLEDGEMENTS

We would like to acknowledge all of the following people who have made considerate contributions to our design and its implementation: Steven Laboe – MS Power Company, Alan Xie – MSU Chemical Engineering, Dr. Hossein Toghiani – MSU Chemical Engineering, and Bill Buchanan – Senior Engineer Advisor. We would also like to thank Dr. Joe Picone and Dr. Georgios Lazarou. Without the help of these individuals our design would not have been possible.

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