Design Specification for

Wireless Ultrasonic Waterflow Monitoring System

Project Team:

Timbo Yuen
Eric Lo
Ehsan Arman
Ye Lin
Babak Razzaghi

Contact Person:

Ehsan Arman
eaa14@sfu.ca

Submitted to:

Dr. Andrew Rawicz – ENSC 440
Steve Whitmore – ENSC 305
School of Engineering Science
Simon Fraser University
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Executive Summary

The Wireless Ultrasonic Waterflow Monitoring System is a system equipped with the capability to measure water flow rate and detect water leakage. This is of particular importance because water leakage is an unpleasant by-product of some water flow systems and it is to be avoided almost all the time. The system is designed in such a way to ensure a proper display of flow rates at various time intervals and compares these values at all times against a certain flow rate threshold allowing for leakage detection. The data collected will then be interpreted by human readable GUI application.

The development of the Wireless Ultrasonic Waterflow Monitoring as a final functioning product requires a thorough analysis of the design features. The attached document contains the design specifications required for product development. In the design procedure, GreenSense Systems has selected the most appropriate methods for integration and implementation of all software and hardware components needed for a smooth and steady operation. Components such as transmitting and receiving units require diligent software and hardware implementation as they would be interfacing with other units present including the Arduino board.

There are specific software and hardware development stages that must be proceeded with in order to obtain a complete design process and they include the following:

- Transceiver system implementation(including PSpice schematics) - Software Implementation
- Transceiver wiring/pin connections- Hardware Implementation
- Ultrasonic Flow Sensor mechanical and electrical connections - Hardware Implementation
- Arduino Microcontroller Programming - Software Implementation
- GUI application for Personal Computer - Software Implementation

During the crucial stages of software and hardware implementation, the design specifications will be referenced by GreenSense Systems team members to ensure that all the requirements specified in this document have been met. Furthermore, this document has been written to meet all safety standards as outlined by the North American product standards.

Glossary

NDT non-destructive testing

F Nominal Frequency

PF Peak Frequency

BCF Bandwidth Center Frequency

BW Bandwidth

PW Pulse Width

S Sensitivity

SNR Signal to Noise Ratio

MCU Microcontroller

KHz Kilohertz, One thousand hertz.

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1 - Introduction

The Wireless Ultrasonic Waterflow Monitoring System will accurately measure the amount of water flowing through an industrial water pipe and sends data to a PC via wireless transmission. By using transit time flow measurement, flow rate can be calculated by using the time the ultrasonic beam is transmitted and the time it arrives at the ultrasonic transducers. Having measured the downstream and upstream transit times of the transducers, the Wireless Waterflow Monitoring System measures the water flow within the pipe. For flows falling below a threshold flow rate the system will emit and alarm sound to notify the user of water leakage detected within the pipe. The development of the final working system is an involved and detailed process of both software and hardware implementation that unifies all components working together.

1.1 - Scope

This document describes the design specifications for product implementation which are to be met by GreenSense Systems in order to have a functioning Wireless Waterflow Monitoring System. These sets of requirements are intended to fully describe all the stages in hardware and software design as well as the interfacing of the device with a personal computer. The design requirements specified for the Wireless Ultrasonic Waterflow Monitoring System will be used throughout the design process.

1.2 Intended Audience

The design specifications are primarily intended for use by all members of GreenSense Systems as well as Enginuity Consulting LTD. The product manager shall refer to this document as well as the functional specifications as a guideline for overall design goals and a guide when developing and implementing the product. This document will also provide some insight into the level of complexity involved in the design for those who are interested in designing the final system.

2 - System Requirements

The system requirements for the “Wireless Ultrasonic Waterflow Monitoring System” are presented in this section.

2.1 - System Overview

The GreenSense Wireless Ultrasonic Waterflow Monitoring System measures the rate of flow in a pipe based on the ultrasonic Transit-time theory. A typical transit-time flow meter operates based on the time difference that ultrasonic waves take to travel between transducers. The flow measuring is made by releasing the ultrasound waves in the same and opposite direction of the flow and obtaining the time difference between two directions. The signals will be processed by Arduino microcontroller. After analysing, the data will be transmitted to receiver and then will be displayed on the users' computers. The output may be presented either by figures or by graphs. The data can be stored in memory, analysed, and used for further usages such as leakage detection and pipe ruptures.

In case of leakage, the users will be informed appropriately. If ruptures have been detected, the system will alarm and inform the users of an emergency situation in the system. This is done through the GUI.

In GreenSense system, the sensors will be mounted outside of the pipes without any intrusion into the pipes (clamp on method). In order to work efficiently, the transducers should be situated in specific distance from each other. In addition, the system works accurately when the transducers are installed in sufficient distance (proportional to the pipe diameter) from the obstacles along the pipes such as faucets, elbows, and pumps.

The transceiver unit will transmit and receive over 802.11b Wi-Fi wireless transmission to communicate the water flow data from the Arduino Uno microcontroller to a personal computer.

The system block diagram is shown in Figure 2.1.

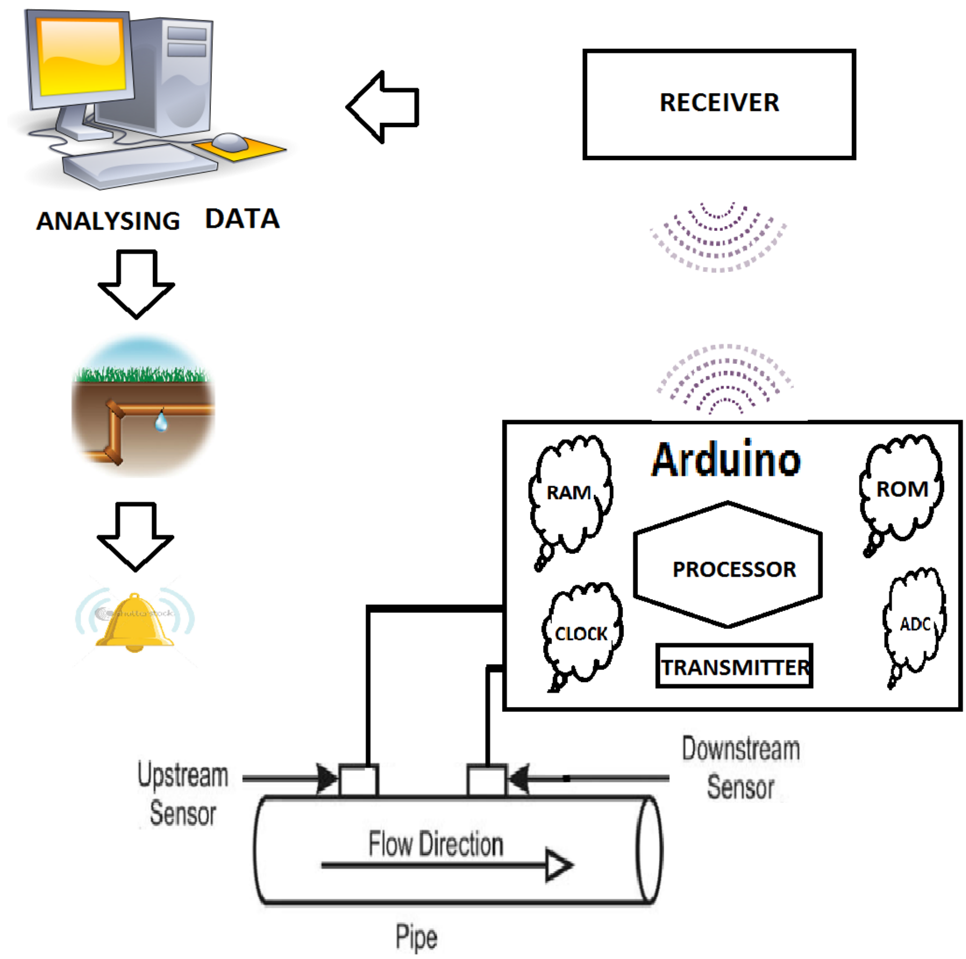


Figure 2.1 - System Block Diagram [12].

In Figure 2.2, it shows the flow chart of the system.

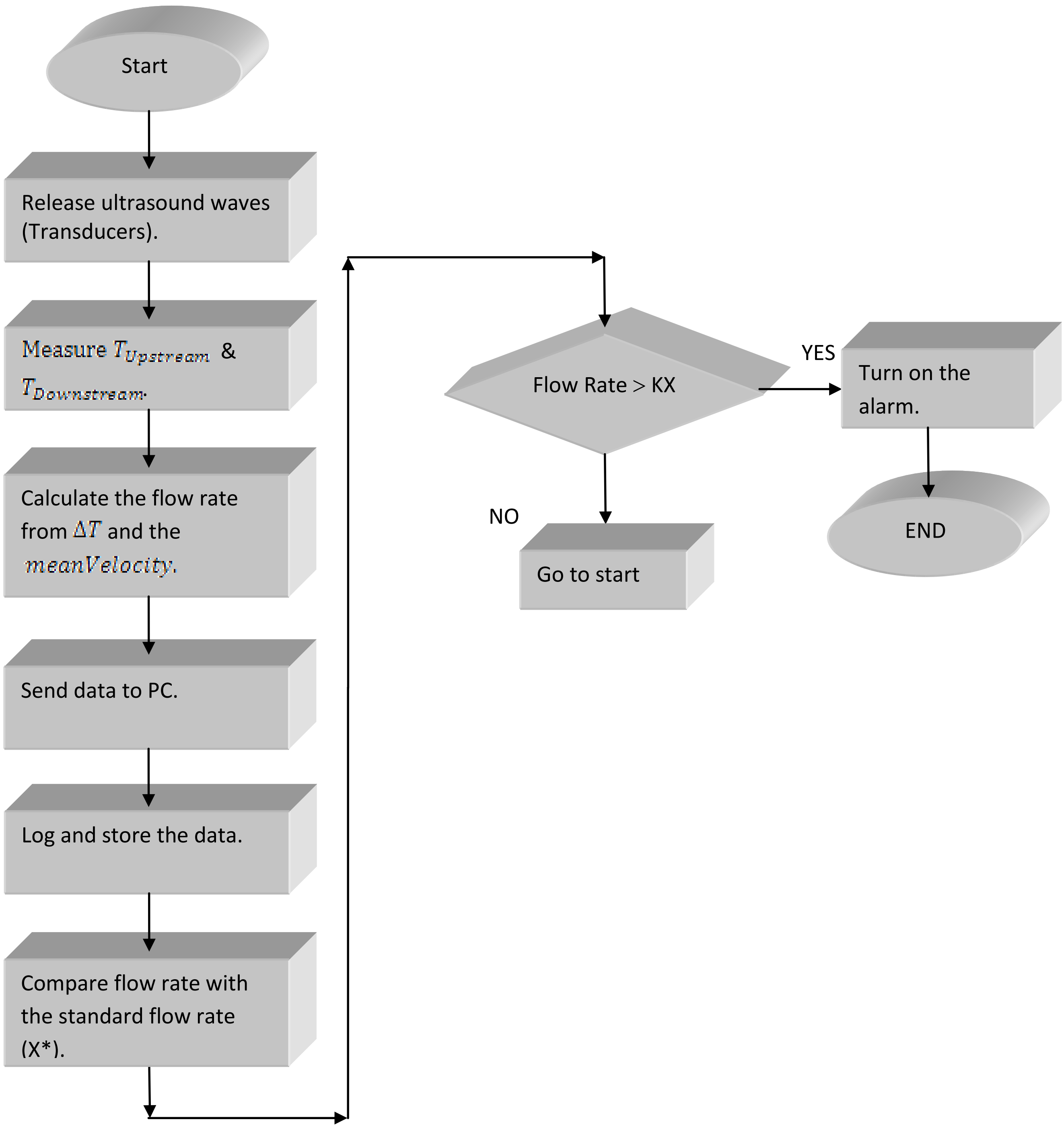


Figure 2.2 - System Flow Chart (*Please note that K and X are design factors)

3 - Ultrasonic Transducer Design

3.1 - General Information

3.1.1-Ultrasound Theory

Ultrasonic, which came from the Latin words ultra (beyond) and sonic (sound), refers to sound waves that vibrate more rapidly than the human ear can detect. A human ability to hear the sound is in the range of 20 Hz to 20 KHz [1]. Ultrasonic waves consist of frequencies greater than 20 kHz. These waves behave in a similar manner to audible sound (for example, both need a medium to travel through); however, they have a much shorter wavelength. Ultrasonic waves are employed in many applications such as plastic welding, medicine, biomedical, jewellery cleaning, pipe inspection, and non-destructive testing known as NDT [2].

The Acoustic Spectrum is shown in the figure below.

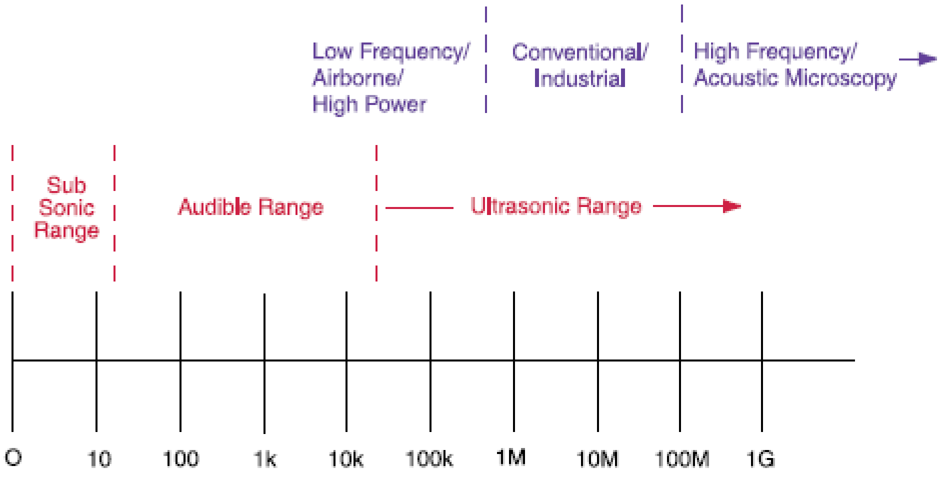


Figure 3.1 - The Range of Sound Beam [3]

In order to generate ultrasonic sound, the electric energy should be converted into the mechanical oscillation energy [4].

3.1.2-Transducers

A transducer is any device that can transform one kind of energy into another form. For instance, a speaker is a transducer because it can convert electrical energy into sound energy, or light bulb is considered as a transducer since electrical energy can be converted into light and heat energy [6]. Therefore, an ultrasonic transducer converts electrical energy to mechanical energy, in the form of sound [3]. Piezoelectric converters are the most common sources to produce ultrasonic waves [7].

Piezoelectric Effect

A piezoelectric substance can generate mechanical movement when subjected to an electric field [7], [8]. Conversely, it can make an electric charge when a mechanical stress is applied [8]. The piezoelectric effect can be observed in the symmetrical crystals which have the same polar axis (a conceptual line) through the center of negative and positive charges on the molecule [8].

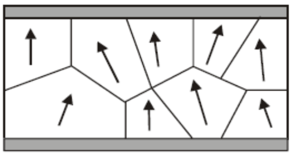


Figure3.2: Symmetrical Crystals [8]

The piezoelectric effect is demonstrated in below:

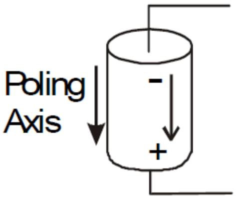
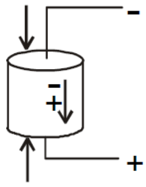
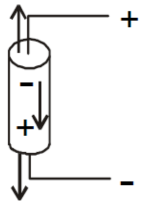
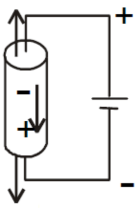
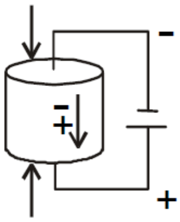
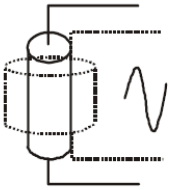
		
Without any stress and charge	The material is compressed ; a voltage is generated (same polarity)	The material is stretched; a voltage is produced (opposite polarity)
		
A voltage is applied; (opposite polarity) the material is expanded	A voltage is applied; (same polarity) the material is compressed	An AC signal is applied; Vibration is created (same frequency as the signal)

Figure3.3: piezoelectric effect [8].

Acoustic Parameters of an Ultrasonic Transducer

Acoustic parameters are measured by characterizing the reflected or transmitted ultrasound from a designated target or a reference medium. They are described in the following table [9]:

ACOUSTIC PARAMETER	DEFINITION
Nominal Frequency (F)	This is identified on the transducer housing.
Peak Frequency (PF)	This is the highest frequency response measured from the frequency spectrum.
Bandwidth Center Frequency (BCF)	This is an average of the lowest and highest points at a –6dB level of the frequency spectrum.
Bandwidth (BW)	This is the difference between the highest and lowest frequencies at a –6dB level of the frequency spectrum, also identified as the % of BCF or of PF.
Pulse Width (PW)	This is the time duration of the time domain envelope that is 20dB above the rising and decaying cycles of a transducer response.
Sensitivity (S)	S (dB) = -20 Log V_x/V_0, where V_0 is the excitation pulse in volts, and V_x is the received signal in volts. Sensitivity, also known as loop sensitivity or loop gain, is the function of the medium in which the test is performed.
Signal to Noise Ratio (SNR)	SNR (dB) = 20 Log V_x/V_n, where V_x is the received signal amplitude in volts, and V_n is the noise floor in volts. SNR is determined without signal processing. SNR measured in this manner also includes the noise associated with measuring instruments, cables, etc.

Table 3.1: Acoustic Parameters of an Ultrasonic Transducer [9]

3.2- Common Types of Ultrasonic Flow Meters

3.2.1-Doppler

In this method, ultrasonic sensors, which are placed outside the pipes, use reflected ultrasonic sound to measure the fluid velocity. Technically, dopler flow meters are based on frequency shift.

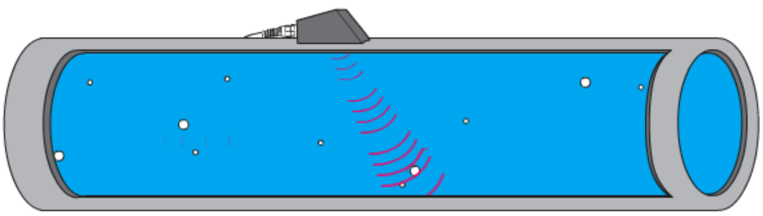


Figure 3.4: Doppler Ultrasonic flow meter ,retrieved from (http://www.greyline.com/howitwk.htm)

However, this technique is only suitable for liquids with solids or gas bubbles such as slurries, sludge, and wastewater which may damage regular flow meters.(Greyline Instruments. http://www.greyline.com/howitwk.htm)[10]

3.2.2-Transit Time

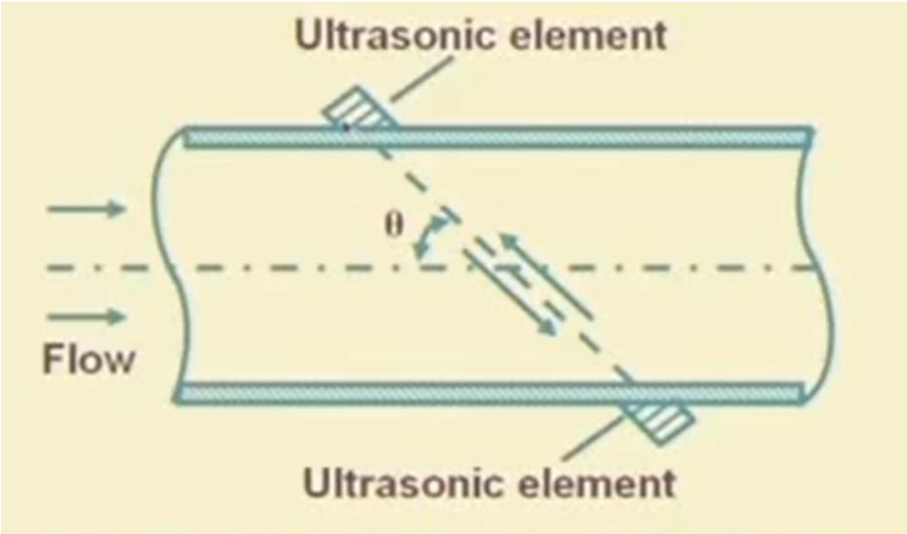


Figure 3.5: Transit-time Flow Meter, Z Model [11]

The time which is travelling between two sensors is different due to the fluid flowing through the pipe. The measurement of the time difference gives the flow velocity[11].

$$t_F = \frac{L}{c + V\cos\theta} \qquad (3.1)$$

$$t_R = \frac{L}{c - V\cos\theta} \qquad (3.2)$$

Where, t_F is the time that sound beam takes to travel to the second sensor, and t_R is time that sound needs to be received by first sensor ,c is the velocity of sound in the fluid, V is the velocity of the fluid, L is the distance between ultrasonic transmitter and receiver , and θ is the angle between the ultrasonic beam and axis of the fluid flow.

The time differenceΔT is equal:

$$\Delta T = t_F - t_R = \frac{2VL\cos\theta}{c^2 - V^2\cos\theta} \quad (3.3)$$

If the receipt pulse is used to trigger the transmitter to emit the sound beams; therefore, the frequency of the forward and return pulse trains are given by:

$$f_F = \frac{c + V\cos\theta}{L} \quad (3.4)$$

$$f_R = \frac{c - V\cos\theta}{L} \quad (3.5)$$

$$\Delta f = f_F - f_R = \frac{2V\cos\theta}{L} \quad (3.6)$$

$$\therefore \quad V = \frac{L\Delta f}{2\cos\theta} \quad (3.7)$$

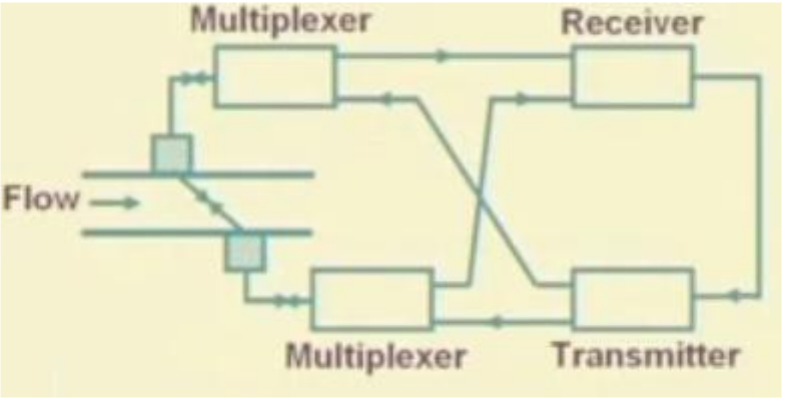


Figure 3.6: The circuit that generates trains of forward and return pulse [11]

In order to use the above equations, this circuit, which generates the forward and return pulse trains should be designed[11].

Circuit Description

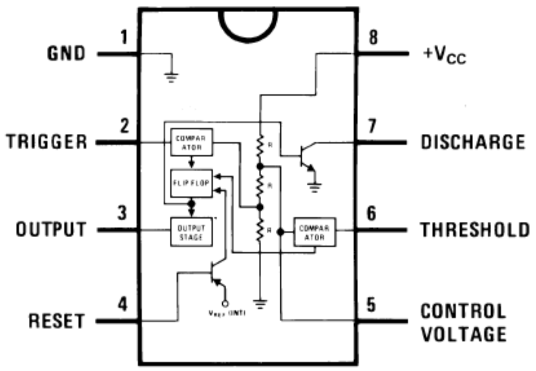


Figure 3.8- Pin Diagram of LM555 from its National Semiconductor Datasheet

The above circuit in Figure 3.8 is for driving the ultrasonic transducer with a 40 kHz square pulse. The ultrasonic transducer is connected to the circuit on the right of above Figure and it appears as a speaker element. The resistors and capacitors of the circuit are tuned to produce the 40 kHz square pulse signal along with the 555 timer IC. With the setup above in Figure 1, the 555 timer IC is configured to operate in its astable mode. As the 555 timer IC is in its astable mode, the output, pin 3, produces a continuous square pulse given that the reset pin, pin 4, is held high. If pin 4 is at 0V, the pulse train stops and so the output signal of the 555 timer IC no longer producing a square pulse. The +12V near the top of the figure is the Vcc voltage supply to the circuit. There is a bipolar junction transistor and a resistor, R_3, placed after the 555 timer to amplify the voltage of the output signal from the 555 timer.

Theory

In this circuit, capacitor C_1 charges through resistors, R_1 and R_2, in order to generate enough voltage to trigger an internal comparator to toggle the output flip-flop. After the flip-flop is switched on, the flip-flop discharges C_1 through R_2 into pin 7, which is the discharge pin. When C_1's voltage becomes low enough, another internal comparator is triggered to toggle the output flip-flop. This once again allows C_1 to charge up through R_1 and R_2 and the cycle starts all over again.

The charge up time of C_1 is in Equation 4.1.

$$t_1 = 0.693\ (R_1 + R_2) * C_1 \tag{3.8}$$

The discharge time of C_2 is shown in Equation 4.2.

$$t_2 = 0.693\ (R_2) * C_1 \tag{3.9}$$

Thus, the total period of one cycle is in Equation 4.3.

$$t_1 + t_2 = 0.693\ (R_1 + 2R_2) * C_1 \tag{3.10}$$

The frequency f of the output wave is the reciprocal of this period, and is therefore given by Equation 4.4.

$$f = \frac{1.44}{(R_1 + 2R_2) * C_1} \tag{3.11}$$

Application

We note that it was possible and tested with code manipulation of the Arduino Uno microcontroller, we were able to produce a 2.5V 40kHz square pulse, but the reason we are using an analog circuit to drive the ultrasonic transducer to transmit the 40kHz pulse is because it is to remove the workload on the microcontroller. Also, by removing the dependency of producing this square wave from the microcontroller, the spare processor cycles or the spare timers on the Arduino Uno can be subsequently used for the calculating, writing data, reading data, and wireless transmission handling.

3.3-Electronics Design

3.3.1-Transmitting Circuit Design

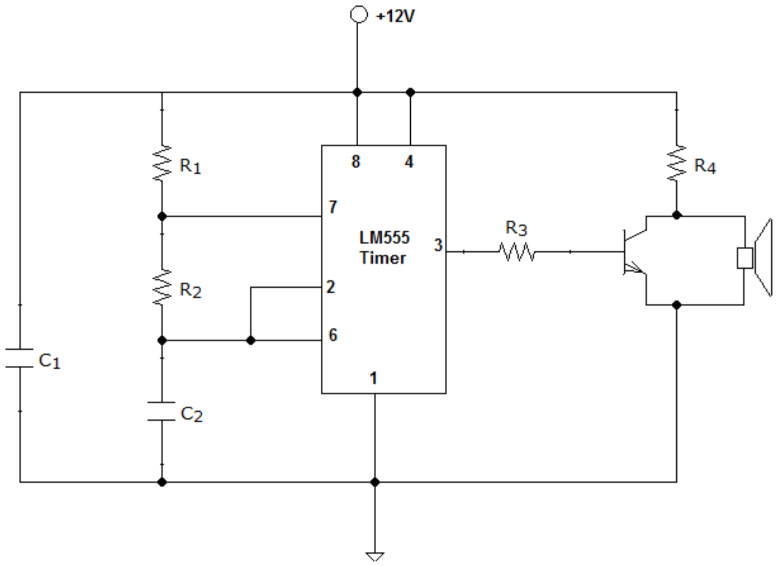


Figure 3.7: transmitting circuit

3.3.2-Receiving Circuit Design

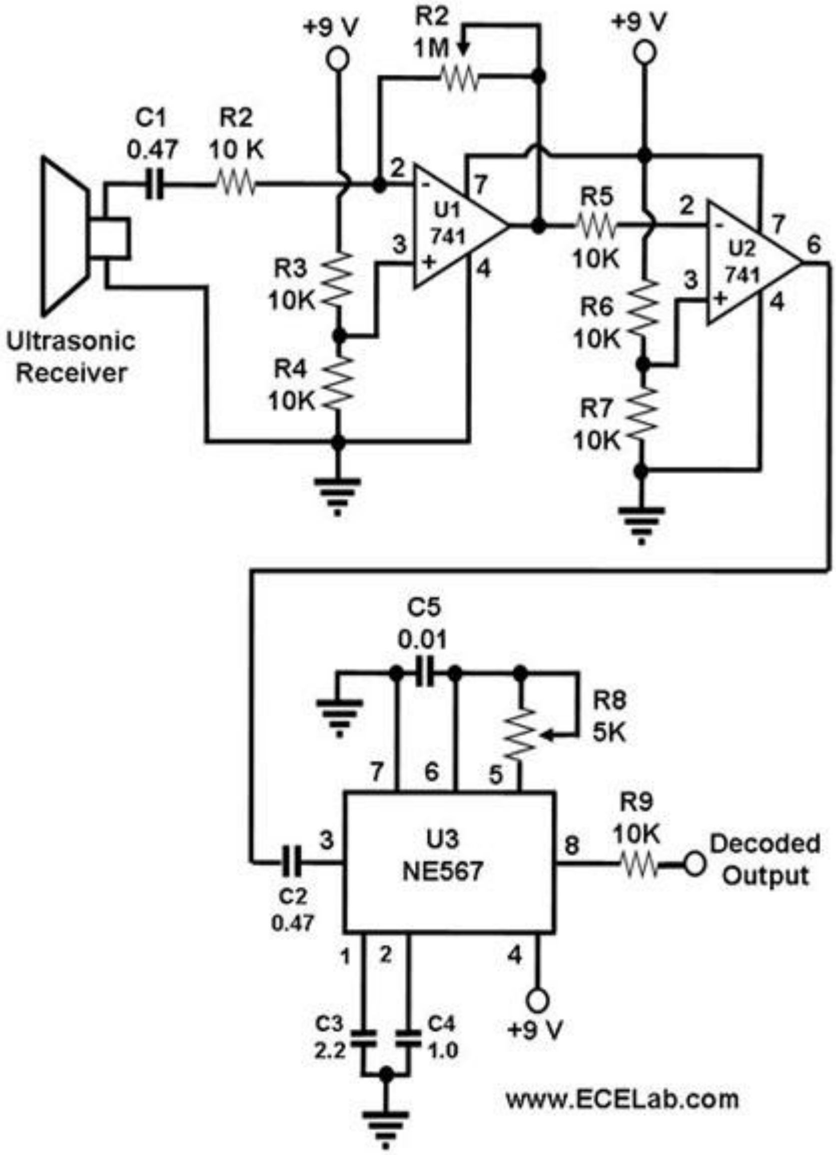


Figure 3.9: receiving circuit

This is the receiving circuit to receive ultrasonic signal from the air. The signal is generated by a matched ultrasonic transmitter. The receiver in this circuit is able to vibrate optimally at about 40 kHz. The 40kHz signal can be transmitted by the transmitting circuit we talked about above. The receiver is able to generate electric pulse when it detects 40kHz input. These electric signals are amplified by the two op amps in the circuit, the amplified output of which are fed into the

567 IC, which is a PLL decoder. This decoder is able to generate output when it detects 40kHz input signal.(we set 40kHz as its set frequency). The output of the PLL decoder will go to the microcontroller. We use capacitor for the reason of filtering the noise when the signal goes into the decoder.

We are using the NE567 as the PLL tone decoder. The NE/SE567 tone and frequency decoder is a highly stable phase-locked loop with synchronous AM lock detection and power output circuitry. Its primary function is to drive a load whenever a sustained frequency within its detection band is present at the self-biased input. The bandwidth center frequency and output delay are independently determined by means of four external components. The NE567 decoder has high stability of center frequency and has high out-band signal and noise rejection. These features are important to wireless communication. Below is the pin diagram of NE567 PLL tone decoder.

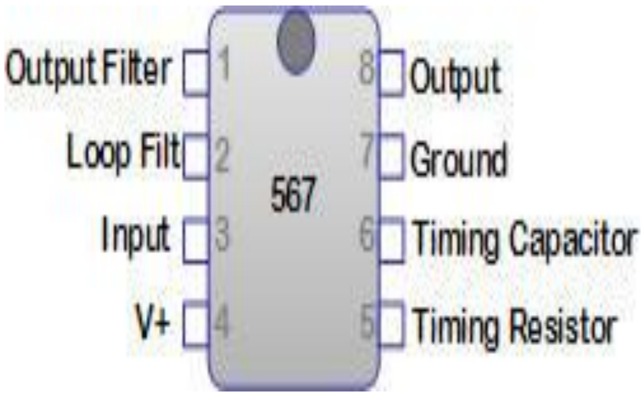


Figure 3.10: NE567 PLL tone decoder

In our receiving circuit we will connect the input signal to pin3 and get out output signal in pin1 as the output from the pin1 had been filtered. Thus we can get cleaner signal from there. The MCU is able to detect the signal in square wave.

Below is the receiving circuit we designed on PSPICE. We try to use the PSIPCE to simulate the receiving circuit. We assemble the circuit as in diagram and Provide 9V of DC supply to check the working. We try to measure the frequency and voltage in the output node to check if this circuit is able to generate 40kHz signal and amplified output (should be above 5v) voltage. If everything is correct we are going to build our real circuit on breadboard based on this simulation.

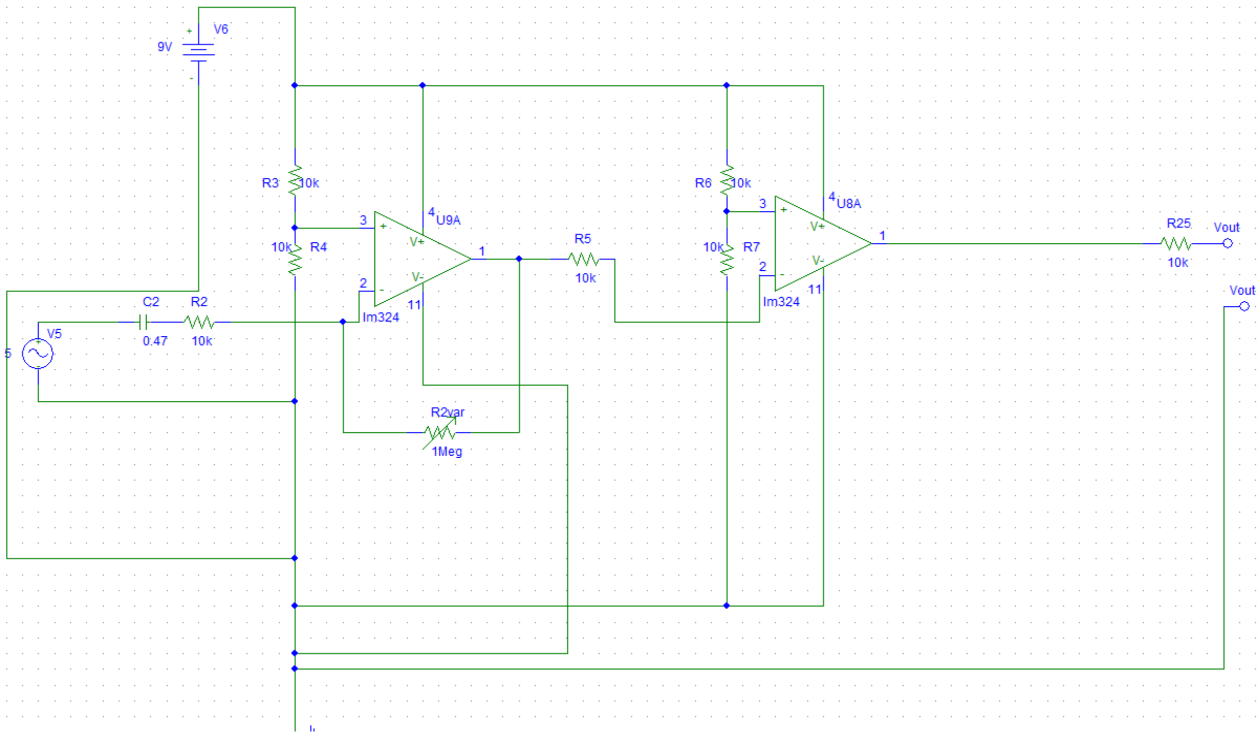


Figure3.11: GreenSense PSPICE test

4- Microcontroller Design

Below is the pin map for Arduino Microcontroll. We have not start working on programming the microcontroller. We just got some basic idea about how to programming the microcontroller for our purpose in the project. We will use the Arduino to calculate and analyze all the formula and data sending from the transceiver circuit and transfer the data to computer.

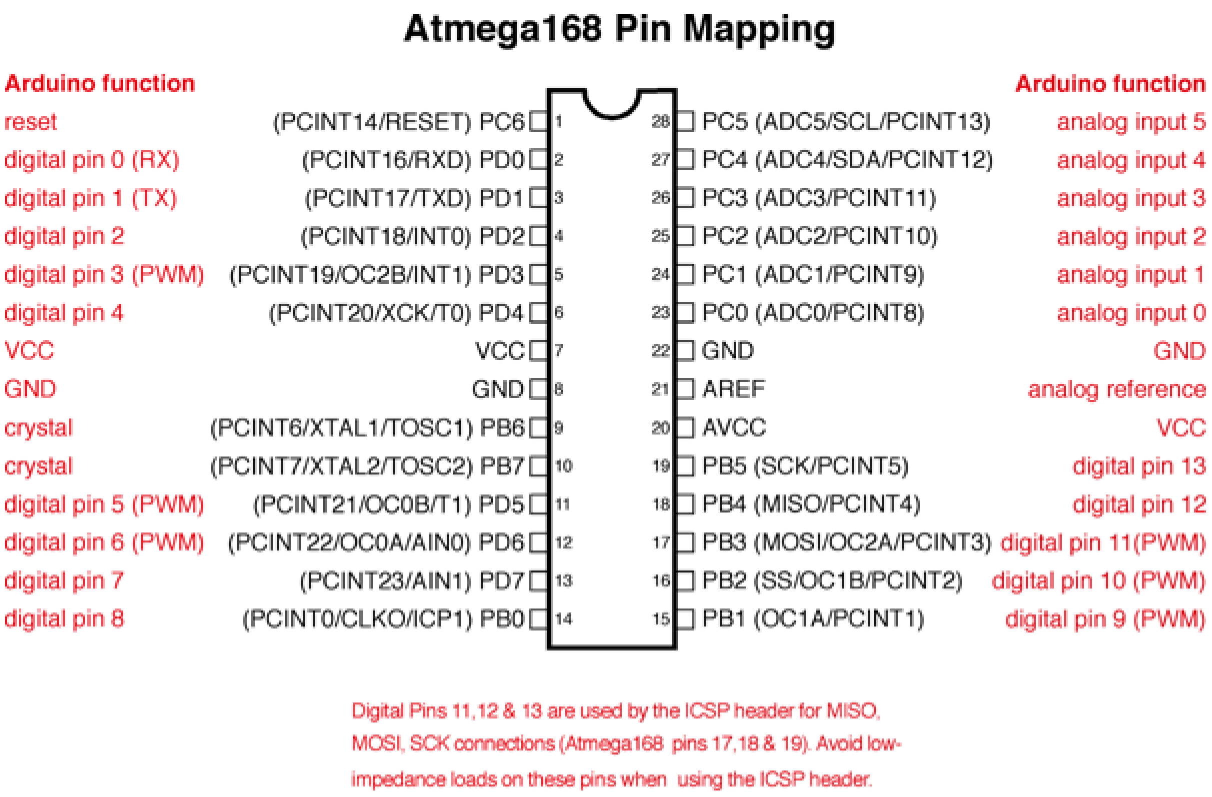


Figure 4.1: Atmega168

Below is the code of setup() and loop() function. The setup() function is to initialize variables, pin modes, start using libraries, etc. The loop () function is able to loop consecutively in order for my program to respond and change. We will put all execution statements and functions in the loop() function.

.

```
int buttonPin = 3;

// setup initializes serial and the button pin
void setup()
{
 beginSerial(9600);
 pinMode(buttonPin, INPUT);
}

// loop checks the button pin each time,
// and will send serial if it is pressed


void loop()
{
 if (digitalRead(buttonPin) == HIGH)

   serialWrite('H');

 else

   serialWrite('L');

 delay (1000);
}
```

Below is the code for specifying the input pin and read date from the input pin that we assigned. Our input pin is analog signal coming from the transmitter circuit. Our pin should in range between PC5 to PC0. Our put signal is digital signal that goes directly to computer. In this case our output pin should be PD0 to PD4.

```
int analogPin = 3;     //we define the pin 3 as our input pin.
int val = 0;           // we initialize the variable.
void setup()
{
 Serial.begin(9600);          //  setup serial
}
void loop()
{
 val = analogRead(analogPin);    // read data from the input pin 3
 Serial.println(val);             // debug value
}
```

5-Wireless Transceiver Design

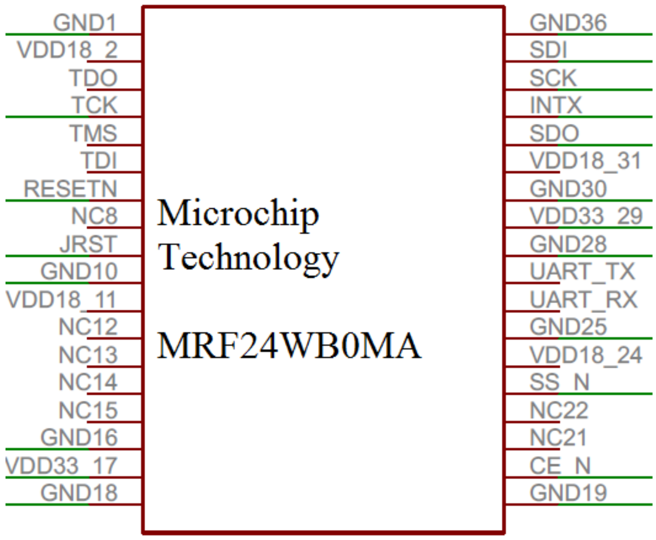


Figure 5.1 - Wireless Transceiver Unit MRF24WB0MA's Pin Diagram

5.1 - Wireless Transceiver Overview

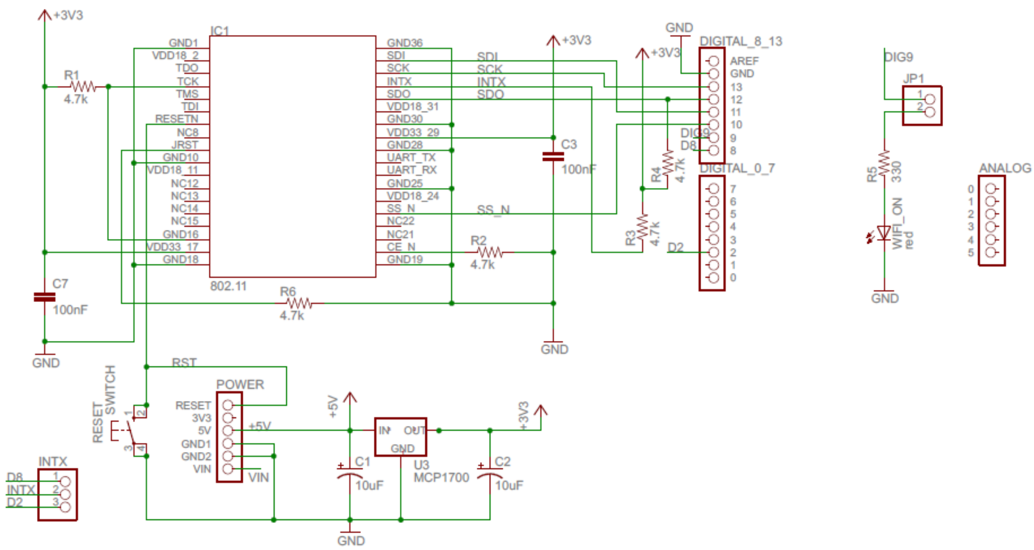


Figure 5.2 - Schematic Diagram of CuHead WiFi Shield from LinkSprite

The wireless transceiver is the CuHead WiFi Shield made by LinkSprite. The schematic of its PCB stackable headers and its connections to the MRF24WB0MA transceiver unit can be seen in Figure 6.2. It is an expansion or add on shield specifically built for Arduino Uno, our microcontroller. It uses Serial Peripheral Interface (SPI) for host communication. This operates in full duplex mode and communicates with microcontroller in a master and slave mode. The microcontroller, Arduino Uno, is the master device. When it is attached to the microcontroller, it features stackable header pins, making all the pins reusable from the microcontroller. It has 802.11b wireless transmission by using an integrated PCB antenna is provided within Microchip's MRF24WB0MA chipset. The TCP/IP stack for network communication is available through WiServer library provided from AsyncLabs' wiki webpage. The usage of the TCP/IP stack requires ATMEGA328 chipset and this requirement is met from our Arduino Uno microcontroller which features that chipset.

5.2 - Wireless Functional Specifications

The operation of the transceiver

5.3 - Code

```
#include <WiShield.h>

#define WIRELESS_MODE_INFRA     1
#define WIRELESS_MODE_ADHOC     2

// Wireless configuration parameters ----------------------------------------
unsigned char local_ip[] = {192,168,1,2};    // IP address of WiShield
unsigned char gateway_ip[] = {192,168,1,1};       // router or gateway IP address
unsigned char subnet_mask[] = {255,255,255,0};    // subnet mask for the local network
const prog_char ssid[] PROGMEM = {"ASYNCLABS"};          // max 32 bytes

unsigned char security_type = 0;    // 0 - open; 1 - WEP; 2 - WPA; 3 - WPA2

// WPA/WPA2 passphrase
const prog_char security_passphrase[] PROGMEM = {"12345678"};    // max 64 characters

// WEP 128-bit keys
// sample HEX keys
```

```
prog_uchar wep_keys[] PROGMEM = {

0x01, 0x02, 0x03, 0x04, 0x05, 0x06, 0x07, 0x08, 0x09, 0x0a, 0x0b, 0x0c, 0x0d, // Key 0

0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, // Key 1

0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00,0x00,  // Key 2

0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00,0x00   // Key 3

};


// setup the wireless mode

// infrastructure - connect to AP

// adhoc - connect to another WiFi device

unsigned char wireless_mode = WIRELESS_MODE_INFRA;

unsigned char ssid_len;

unsigned char security_passphrase_len;

//---------------------------------------------------------------------------


void setup()

{

	WiFi.init();

}

// This is creates the webpage which will be operated by the webserver

const prog_char webpage[] PROGMEM = {"HTTP/1.1 200 OK\r\nContent-Type: text/html\r\n\r\n<center><h1>Hello World!! I am WiShield</h1><form method=\"get\" action=\"0\">Toggle LED:<input type=\"submit\" name=\"0\" value=\"LED1\"></input></form></center>"};

void loop()
```

```
{
        WiFi.run();
}
```

5.4 - Application

We note that it was possible and tested with code manipulation of the Arduino Uno microcontroller, we were able to produce a 2.5V 40kHz square pulse, but the reason we are using an analog circuit to drive the ultrasonic transducer to transmit the 40kHz pulse is because it is to remove the workload on the microcontroller. Also, by removing the dependency of producing this square wave from the microcontroller, the spare processor cycles or the spare timers on the Arduino Uno can be subsequently used for the calculating, writing data, reading data, and wireless transmission handling.

6-System Testing Plan

6.1 Overview

The system will be tested separately. First, we will test the function of each component in the system. After this, the integrating test will be executed. With this plan, we are able to diagnose the problems more accurately; hence, we can increase the speed of the testing process.

Component Test

- We construct the circuitry of transceiver on P-Spice and simulate the circuit to see if we acquire desired output voltage.

- We test the code of microcontroller to ensure the microcontroller is able to change the analog signal to digital signal.

- The computer must be able to read data from sensor and perform input data calculation according to the assigned time frame.

Integration Test

- All the components will be integrated together. Each component must match other components. In this step, we ensure the function of the system.

Extreme Case Test

- In this test, we want to test the system under extreme case.
  - High/Low water temperature in the pipe: The temperature of the water inside the pipe should not affect the performance of sensor. The testing water temperature will be from 0 degree to 70 degree Celsius.

  - High/Low water pressure in the pipe: The sensor must measure the water flow accurately even the velocity of water flow is extremely high or low. The velocity should be within 1 to 15 litre per minute.

- Water bubble interference: The system must report accurate data even the density of water bubble in the pipe is high. We will increase the number of bubble in the pipe by pumping air into the water.

Signal Strength Test

- We want to test the strength of the signal of transmitter and receiver.
  - Distance test: The distance between transmitter and receiver will be increasing gradually. We want to ensure under reasonable distance (400 meter), the signal can be sent through transceiver to computer stably.
  - Blocking material test: We will use different material such as concrete, metal, or plastic to shelter the transmitter to see if the transceiver performs normally.

Final Test

- Regular water flow: The speed of water flow will be set to be normal, the computer must be able to present a full detail diagram of the water usage in interval of every five minutes to the user. In this test, only one set of sensor needs to be activated.

- Leakage condition: The speed of water flow will be set to be normal. However, we cut a hole on the pipe in order to create a leakage condition. In this test, multiple sensors must be activated. The reason of that is because we place multiple sensor on the pipe with certain interval in between; by doing this, the computer can diagnose the interval which causes the leakage.

7- Conclusion

This design specification possesses the solution to our function specification. All the components and methods we chosen are for meeting the requirements of our project. We are still working on building and testing the transceiver circuit and we are going to program the microcontroller after the circuit is able to work well. At the same time, the stability and safety has been always within our consideration and it will be ensured. The whole design purposes are expected to be met at the end of the project cycle and we are going to test our device in real environment.

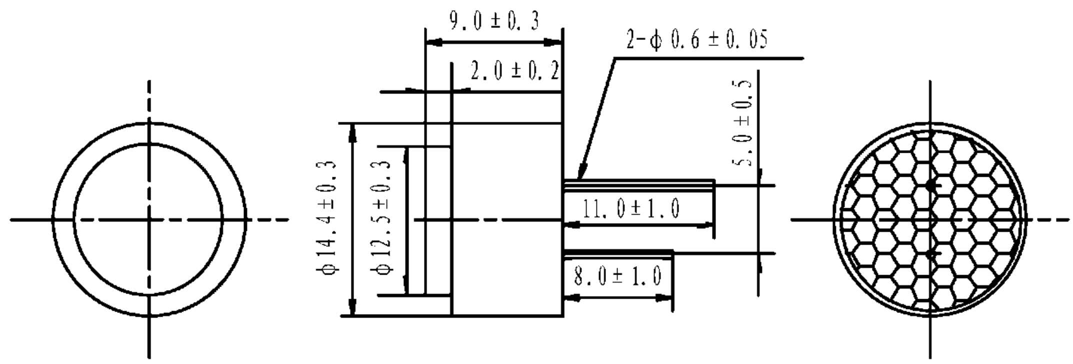
8-Data sheet of PIEZO Ultrasonic Sensor

■MODEL: T/R40-14.4A0-01

■ELECTRICAL SPECIFICATION:

1	Center frequency(KHz)	40±1.0KHz
2	Echo Sensitivity	^200mV (FIG1 SIMULATION TEST CIRCUIT)
3	Decay Time	^ 1.2ms (FIG1 SIMULATION TEST CIRCUIT)
4	Directivity (deg)	70±15
5	Capacitance (pF)	1800 + 15%
6	Allowable Maximum Input Voltage(Vp-p)	140(40KHz) Pulse width 0.5ms, interval 20ms
7	Mean Time To Failure	50000h
8	Operating Temperature(°C)	-40—+80
9	Storage temperature(C)	-40—+85

■APPEARANCE AND DIMENSIONS



■ ENVIRONMENT CHARACTERISTICS

CONDITIONS	STANDARDS
High and low temperature (from-40℃to +80℃at a relative humidity of 30%)	Sensitivity shall not change by more than 30% all of the conditions.
Humidity of 10% to 90% at the temperature of 25 C	All sensitivity shall be within 30% of the specified values after the device is subjected to any or all of the conditions.
Storage at +85 Cfor 96 hours and at -40 Cfor 96hours followed by a normalization period at 25 C. As shown in FIG.3.	
Operation at 95% relative humidity and 40 Cfor 100 hours, followed by a normalization period of 24hours at 30% and 25C.As shown in FIG.4.	
Vibration at 10Hz to 55Hz ,1.5mm amplitude. 1 minute sweep. X,Y,Z,3 each axis for 3 hours. As shown in FIG.5	

■ TESTING INSTRUMENT AND CONDITION LIST

No.	Testing item	Testing Equipment/Methods	Testing conditions
1	Resonant Frequency	Piezoelectric Transducer Resistance Testing System II	Testing temperature :25±2°C
2	Echo Sensitivity	According to Fig. 1 Test Circuit	Distance to obstacle: 1 meter , Obstacle: organic glass board with 20CM*20CM*1.0CM 1.The inductance :8mH, Q m Value: 60-80, Pulse : 20 2.The Minimum detect distance>35cm 3.The acoustic system without coupling
3	Ring Time	According to Fig. 1 Test Circuit	The sensor surface is covered by 100mm thickness of sponge 1.The inductance :8mH,Qm Value: 60-80, Max Pulse <20 2.The Minimum detect distance>35cm 3.The acoustic system without coupling
4	Directivity	According to Fig.1 & Fig. 2 Test Circuit	In normal room temperature, the distance to the ground: 55cm the distance to the obstacle: 50cm the obstacle: diameter of 50mm PVC pipe, the obstacle height: 1 meter Note: there is no other obstacle in a circumference of 1 meter.
5	Capacitance	Digital LC ZL5	Testing temperature :25±2°C
6	Maximum Input Voltage (V p-p)	According to Fig.1 Test Circuit Oscillograph: Tektronix TDS1002	Pulse Width: 0.5mS, Interval :20mS
7	Mean Time to Failure	Aging Equipment AWHY001	Testing temperature :25±2°C

8	Operating Temperature(°C)	High-Low alternating temperature Cabinet	In normal room temperature, according to the Fig. 4 test circuit
9	Storage Temperature(°C)	High-Low alternating temperature Cabinet	In normal room temperature, according to the Fig. 4 test circuit

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