International Journal of Engineering & Scientific Research
Vol. 6 Issue 8, August 2018,
ISSN: 2347-6532 Impact Factor: 6.660
Journal Homepage: http://www.ijmra.us, Email: editorijmie@gmail.com
Double-Blind Peer Reviewed Refereed Open Access International Journal - Included in the International Serial Directories Indexed & Listed at: Ulrich's Periodicals Directory ©, U.S.A., Open J-Gage as well as in Cabell's Directories of Publishing Opportunities, U.S.A

Sonar System Software and Hardware Development: Fish Finder Application

Sajad Rahmdel*
Yung-Ho Yu**
Gang-Gyoo Jin***

Article Received: 15th July, 2018
Article Revised: 20th July, 2018
Article Accepted: 25th July, 2018

Keywords:

Sonar system;
fish finder;
sonar software development;
sonar hardware development;

Abstract (10pt)

A study of how to develop a sonar system is presented in this paper. A typical sonar system has two sub circuits, namely, transmit path and receive path. On the transmit path, HV (high voltage) pulses are generated and transmitted into the water using a transducer. On the receive path, the echo of the transmitted signal is received. This received signal is then amplified and converted into digital data using an ADC (analog to digital converter). The digital data is then sent to a PC for signal processing. After signal processing, the results are shown in a GUI. The developed GUI also does noise filtering as well as calculating the depth and distance to the detected objects. The proposed sonar system was evaluated in a 1-meter water and a 10-meter shore side water tests. The experiment results were satisfactory and the error in mathematically calculated depth and experimental depth was in acceptable range.

Author correspondence:

Yung-Ho Yu,
Corresponding Author Email Id: **rahmdel.s@gmail.com**

1. Introduction

SONAR is the acronym for SOund Navigation And Ranging. By using a sonar system, one can detect and map objects underwater. Usually, sonar systems have a frequency between 20KHz up to 800KHz. Sonar has several applications including fish finders, ocean floor mapping, and vessel navigation.

Sonar systems fall into two categories, namely, passive sonars and active sonars. In passive sonars, no signal is transmitted and the system only listens and receives echoes. Passive sonars are typically used for military vessels, where the vessel would stay undetectable.

In active sonars, the system transmits a pulse or ping using a transmitter. Then the system waits and listens for the response or echo of the transmitted signal. The echo is captured by a receiver. If the transmitted signal hits an object, such as a school of fish, an attenuated reflection will move backward towards the transducer. This reflection is called echo. When the echo reaches the system, the receiver captures and converts this analog echo into electrical signal. The electrical signal is very weak and contains noise. As a result, the signal is amplified and the noise is reduced. Then, using signal processing, the signal is converted into a GUI which displays the size and location of each detected object. [1]

Several papers and books [2-7] explain both the theory and application of sonar systems. While these studies represent important information about sonar systems, none of them explain the practical process of building the hardware and software of a sonar system. This lack of background in explaining how to build a complete sonar system motivated the researcher to write this manuscript. The purpose of this study is to explain the process to build both the software and the hardware necessary for a sonar system. A prototype of the sonar system was also developed to validate the proposed system. The results showed satisfactory system performance with acceptable distance to detected object error.

*Master Program, Control and Instrumentation Engineering, Korea Maritime and Ocean University, Busan, South Korea

2. Theory of Advanced Sonar Systems

Explaining Main theories of sonar systems including traditional pulse and Continuous Wave, beamforming, Signal-to-Noise Ratio (SNR), and velocity of sound in water are explained in here.

2.1 Traditional pulse and Continuous Wave

The transmitted pulse is divided into two main types, namely, traditional tone burst (ping) and Continuous Wave (CW). The traditional sonar transmits a single powerful ping with a constant frequency into the water column, then it listens for the echo of the transmitted pulse. Typically, traditional sonars transmit high energy pulse but for a very short duration. As a result, the total amount of energy that can be transmitted is limited. In addition, different frequencies reveal different levels of detail. For example, 50Khz frequency can penetrate deeper in water but it provides less detail, however, 200Khz frequency has less penetration but shows more detail. As a result, most traditional sonars use two or three different frequencies to provide better combination of details and depth.

On the other hand, the CW is capable of transmitting longer pulses than the traditional sonar, putting more energy into the water. CW sonars can also generate pulses with varying frequencies as a result they capture better details of the objects inside water. In this study, traditional pulses are used, however, the structure is designed in a way that the system could be upgraded to use CW technology in the future.

In the proposed system, pulses are generated for 10% of the time which the signal needs to reach the sea floor and gets back to the transducer. During the other 90% of the time, the system does not generate any pulse and listens for echoes. For example, if the distance to the sea floor is 10 meters, the system will generate pulses for the time equivalent to 1 meter while listening to the echo for the time equivalent to 19 meters (total distance that the signal travels to reach the sea floor and gets back to the transducer is 20 meters). Also, during the pulse generation, the system cannot receive any echo.

2.2Beamforming

In a sonar system, acoustic waves are transmitted with a specific frequency into the imaging medium (in our case into water). Then the echo of the transmitted wave is received and saved as a function of time and position. The transmission and receive of sound waves are done at the transducer. As a result, using simple trigonometric geometry, the distances through which these waves propagate can be found. This idea is illustrated in Figure 1. The scattered echoes from object with position (x, z) is received by the transducers (τ_1 to τ_N). Some of these echoes are received faster and some others are received with little delay. These echoes are then summed up using the principle of delay-and-sum beamforming to get a better Signal to Noise Ratio (SNR).

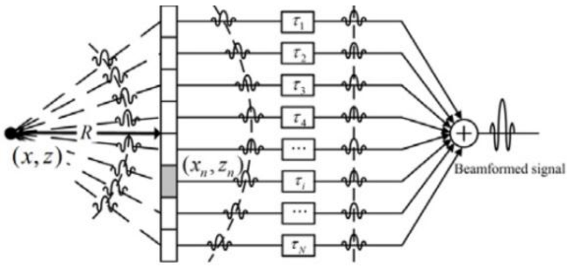


Figure 1: Principle of Delay-and-Sum Beamforming[1]

This principle is explained in more details using an example shown in Figure 2. As shown in the figure, two neighboring and independent transmitted signals from two different transducer elements are displayed in the figure. The red arrow shows the signal transmitted and received from the first transducer element, while the pink one represents the signal from second transducer element. The received waveforms by these two independent channels include separate and different datasets. As seen below, the distances are different, and assuming constant speed of sound in water, the propagation times of the two channels are unequal.
Because this project was our first attempt to create a sonar system, for simplicity, the proposed sonar system does not include beamforming. The AFE5809 hardware used for this study has 8 channels. As a result, the proposed sonar system is capable of using beamforming to improve the Signal-to-Noise Ratio (SNR). That's why the concept of beamforming was explained here.

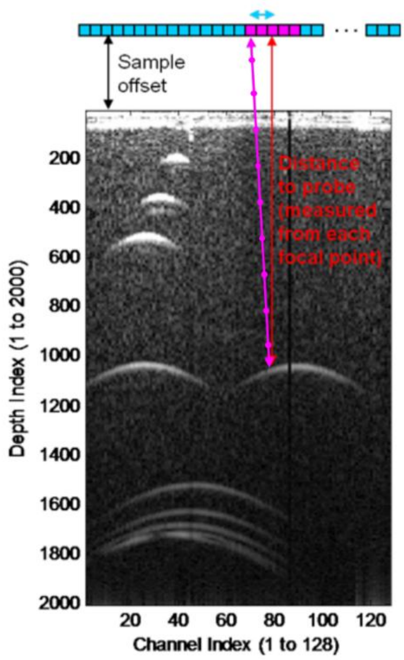


Figure 2: Geometry of Propagation Paths[1]

2.2Signal-to-Noise Ratio (SNR)

There are a number of methods to improve the SNR of a sonar system both in analog and digital domains. Implementing these methods may result in better quality or the range over which the sonar system could be used.

Typically, two reasons cause the low SNR of the received echo. These reasons are the attenuation of the acoustic wave in the medium and the limited power output for wave transmitted by transducer.

A common approach to increase the SNR is by using multiple neighboring channels to capture the echo following the beamforming theory which was explained in the previous section. The difference in timing of the neighboring channels could be cancelled out because the physical location of the transducer elements is known at the time of beamforming. As a result, the delay of the data for different channels are removed and the data are cumulatively summed to achieve higher SNR. By summing the neighboring data, the noises will cancel out each other, as a result better SNR is achieved [8].

2.6 Velocity of sound in water

The velocity of sound in water depends on several factors including water temperature, salinity, and pressure. The speed of sound in sea water is calculated from the following empirical equation:

$$\mathrm{c}(\mathrm{T}, S, \mathrm{z}) = \mathrm{a}_1 + a_2 T + a_3 T^2 + a_4 T^3 + a_5 (S - 35) + a_6 z + a_7 z^2 + a_8 T (S - 35) + a_9 T z^3 \quad (1)$$

where T is the temperature in degrees Celsius, S is the salinity in parts per thousand, z is the depth in meters, and the constants are:

$$\begin{array}{lll} a_1 = 1,448.96, & a_2 = 4.591, & a_3 = -5.304 \times 10^{-2}, \\ a_4 = 2.374 \times 10^{-4}, & a_5 = 1.340, & a_6 = 1.630 \times 10^{-2}, \\ a_7 = 1.675 \times 10^{-7}, & a_8 = -1.025 \times 10^{-2}, & a_9 = -7.139 \times 10^{-13}, \end{array}$$

The velocity of sound in water with 10℃, 1000 Kilopascals, and 3% salinity is calculated to be 1500 m/s. The below figure shows the speed of sound profile in sea water [9].

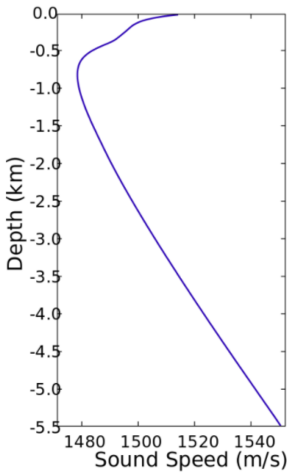


Figure 3: Speed of Sound Profile in Sea Water *[10]*

3. Sonar Prototype Hardware

In this section, it is explained the results of research and at the same time is given the comprehensive discussion. Results can be presented in figures, graphs, tables and others that make the reader understand easily [2], [5]. The discussion can be made in several sub-chapters.

3.1. Sub section 1

Sub section should be written without bold type. The result and analysis are presented by present form. Please avoid too many paragraph in this section.

3.2. Sub section2

Sub section should be written without bold type. The result and analysis are presented by present form. Please avoid too many paragraph in this section.

The proposed sonar system is divided into two separate parts. First part is called transmit path sub-circuit and the second part is called receive path sub-circuit. The sonar system diagram is shown in Figure 4 and each sub-circuit is explained in detail in the following sections.

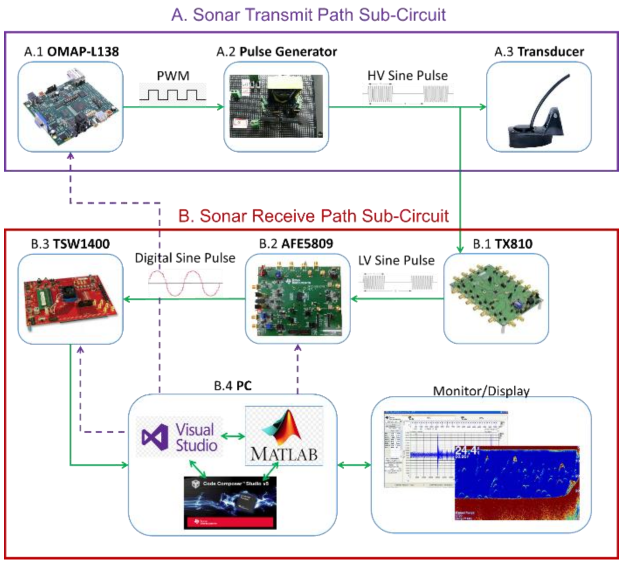


Figure 4: Sonar System Diagram

3.1 Sonar Transmit Path Sub-Circuit

The High Voltage pulse is generated and transmitted in sonar transmit path sub-circuit. Figure 5 illustrates this sub-circuit and each part of the transmit path sub-circuit is explained in more detail below.

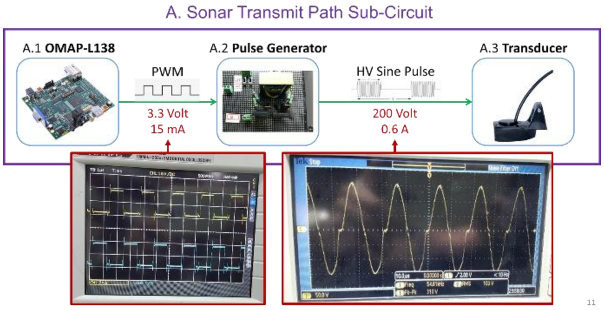


Figure 5: Sonar Transmit Path Sub-Circuit

3.1.1 OMAP-L138

The two Enhanced High-Resolution Pulse-Width Modulator (eHRPWM) of *OMAP-L138* are used to generate two PWM signals. These PWM signals are given as input to *HV Pulse Generator.* The two PWM signals have a frequency of 95 KHz which is proper for our transducer.

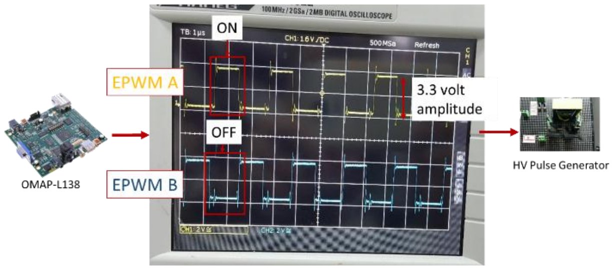


Figure 6: two ePWM signals generated by OMAP-L138 with 95Khz frequency and 3.3 volt amplitude

3.1.2 HV (High-Voltage) Pulse Generator

A custom board was designed to convert the low voltage ePWM generated by OMAP-L138 to high-voltage sine pulse. Below is a photo of this pulse generator.

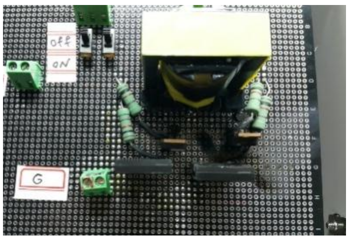


Figure 7: HV Pulse Generator Board

The HV pulse generator has two main inputs. A power input with DC 24V/30A and a pair of ePWM inputs. Two low voltage ePWMs are generated by OMAP-L138. These ePWMs are then connected to the inputs of the custom HV pulse generator. The ePWMs activates two transistors where these transistors in turn will active another two power MOSFETs. The MOSFETs will then transmit the high voltage input into the Transformer. The transformer will then amplify the input voltage, as a result, the input 24 volt will be amplified to about 100 volts (RMS) on the output side of the transformer. A capacitor is then added after the transformer to convert the ePWM shape into the sine shape. Various capacitors with different capacities have been tested to find the best possible sine shape. The schematic of HV pulse generator is shown in Figure 8.

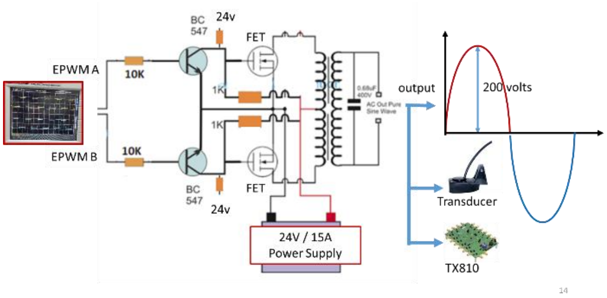


Figure 8: Schematic of HV Pulse Generator

3.1.3 Transducer

Ultrasonic transducers are divided into three broad categories: transmitters, receivers and transceivers. Transmitters convert electrical signals into ultrasound, receivers convert ultrasound into electrical signals, and transceivers can both transmit and receive ultrasound. Our transducer has a frequency of 95 KHz and it requires 300W power. Thetransducer transmits sine pulses into the water. Then it receives the echoes of those pulses and sends them to the TX810 board.

3.2 Sonar Receive Path Sub-Circuit

The echo of the received signal is captured and displayed in PC using the receive path sub-circuit. Figure 9 shows the diagram of this sub-circuit.

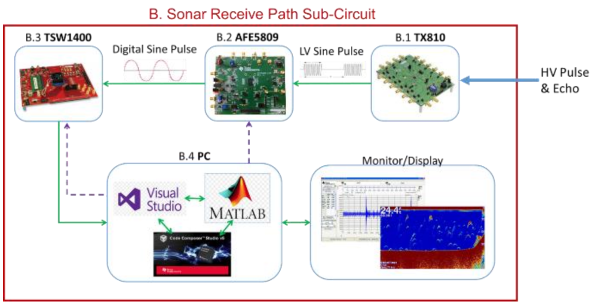


Figure 9: Receive Path Sub-Circuit

Each component of this sub-circuit is explained in detail below.

3.2.1 TX810

The TX810 is a T/R switch which is used to prevent high voltage signals from the HV Pulse Generator directly getting to the ultrasound AFE5809's lower voltage amplifier input pins. This transmit/receive switch alternately connects the HV Pulse Generator and AFE5809 to a shared transducer. When the HV Pulse Generator is active, the resulting high voltage causes the circuit to conduct, shorting together the AFE5809'sterminals to protect it.

The TX810 can prevent high voltages up to ± 100 peak-to-peak volts. For deep ocean depth applications, higher voltage than the maximum of this switch is necessary. As a result, for those applications, we cannot use this switch [11].

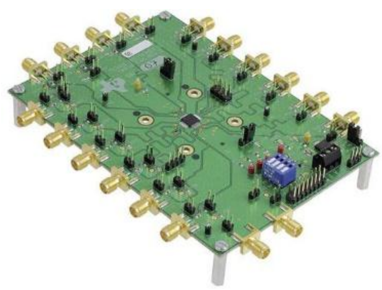


Figure 10: TX810 Board

3.2.2 AFE5809

The AFE5809 device is a highly-integrated analog front-end (AFE) solution specifically designed for ultrasound systems. The AFE5809 has 65 Mega Sample Per Second (MSPS) sampling rating, a 12, 14 or 16-bit Analog-Digital Convertor (ADC), and 8 I/O channels. The AFE5809receives the analog echo of the pulse from TX810. Then, it converts this analog signal into digital signal using the ADC. This digital signal is then given to the TSW1400 as input [12].

Figure 11: AFE5809 Board

3.2.3 TSW1400 EVM

The TSW1400 EVM is a complete data capture circuit board used to capture and analyze the digital output of AFE5809. The TSW1400 EVM features a high speed LVDS bus capable of providing 16-bits of data at 1.5 GSPS. The board comes with 1GB of memory, which provides a 16-bit sample depth of 512 MB. The AFE5809 generates raw ADV values. These values are then transferred to TSW1400 using an LVDS connection. The TSW1400 then captures these raw values and temporarily stores them in its on-board memory. These data are then transferred into a PC using a USB cable for further analysis [13].

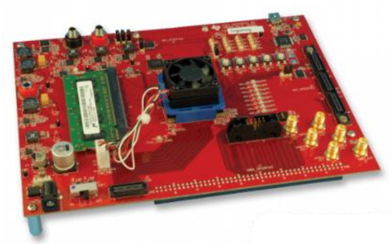


Figure 12: TSW1400 Board

4. Sonar Prototype Software

As shown in Figure 4, the PC controls three components of this sonar system, namely, OMAP-L138,AFE5809 and TSW1400 EVM. A total of five different software were used (Visual Studio, Code Composer Studio, Matlab, AFE5809 GUI, and HSDC Pro). Figure 13 shows the PC software block diagram.

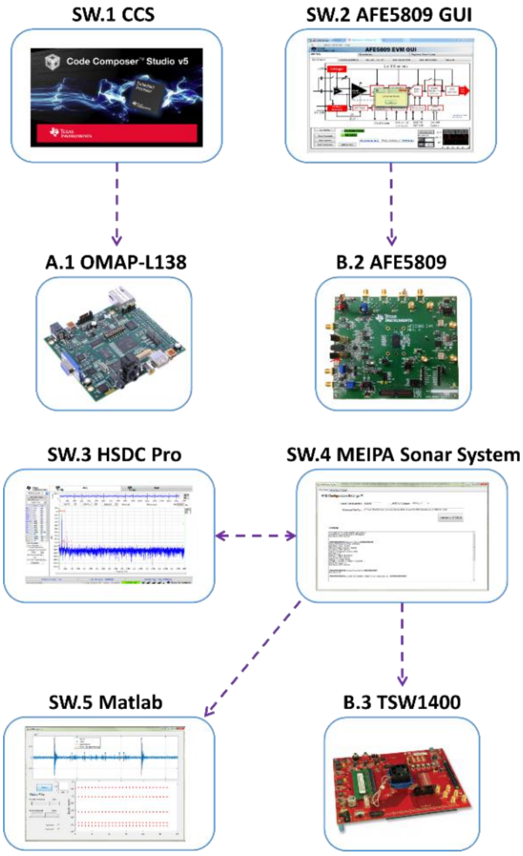


Figure 13: Software Block Diagram

4.1 SW.1 CCS: Control of OMAP-L138

A custom code was written in C++ language to configure OMAP-L138'seHRPWM module and produce two PWM signals.

4.2 SW.2 AFE5809 GUI: Control of AFE5809

Different register values of AFE5809 should be configured to ensure the proper functionality of this module. AFE5809 GUI software which is developed by Texas Instruments was used for this purpose.

4.3 SW.3 HSDC Pro: Control of TSW1400 EVM

Several different register values of TSW1400 should be configured to make sure the board functions properly. As a result, High speed data converter (HSDC) Pro software was used. HSDC Pro provides the tools to connect and capture data from AFE5809 board.

The HSDC Pro software can capture the data from the AFE5809 manually. However, for this application, the whole process should be automated. To achieve this automation goal, Visual C++ was used to make a custom code and GUI. Using this custom code, the process of capturing data from AFE5809was automated. Also, the data was then saved as a .csv file in a directory.

4.4 SW.4 Control GUI:

Using Visual C++, a custom code and GUI, namely, ControlGUI Software, was designed to automate the process of capturing data from AFE5809 and saving the data .CSV file in a folder directory.

4.5 SW.5 Fish Finder GUI: Signal Processing and GUI

Matlab Signal Processing toolbox provides an ideal solution to our signal processing requirements. As a result, the Fish Finder GUI code was written in Matlab Language. A screenshot of this Fish Finder GUI is shown in Figure 15.

Figure 14 illustrates the signal for a single pulse and the received echo of the pulse.

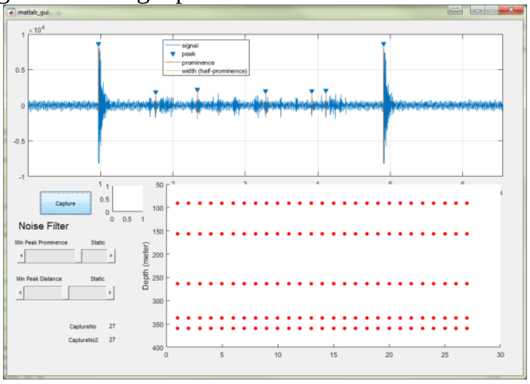


Figure 14: Fish Finder GUI, Transmitted pulse and received echo

Figure 15 shows a GUI similar to fish finder products. The developed Fish Finder GUI shows the depth of the sea and the frequency of the signal. The intensity of echo is shown by different colors. For example, for high intensity echo, a red color is shown, while a low intensity echo has a color close to blue.

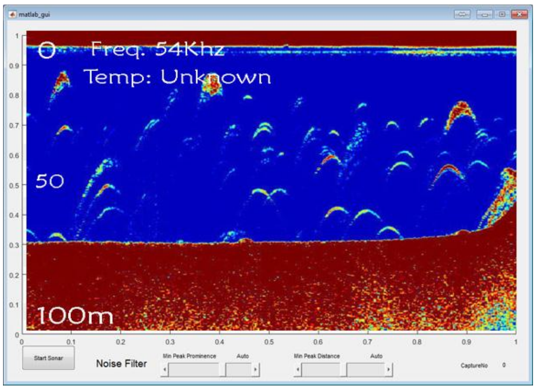


Figure 15: converting ADC values into image maps

4.6 Process of calculating sea floor and fish position

The Fish Finder GUI code calculates the fish position and the floor of the sea. Here is the process:

a. The signal data is received from Control GUI Software, which was explained in previous section.
b. The noise is filtered by using Min Peak Prominence and Min Peak Distance variables. These variables could be adjusted in GUI, as shown in Figure 15.
c. Using signal processing, the local maxima of the echo of the signal is calculated. Each local maxima indicates an object (fish).
d. The time it takes for the sonar wave to hit the object and get back to the transducer is calculated using:

$$\text{Time} = \frac{\textit{Samples Traveled}}{\text{AFE Sampling Rate}} \qquad (1)$$

where Samples Traveled is the number of samples captured from the moment the pulse is generated until the moment the echo is received; and AFE Sampling Rate is 65 MSPS.

e. Then the distance is calculated using:

$$\text{distance} = \frac{\text{SoundVelocity} * \text{Time}}{2} \qquad (2)$$

f. This process is repeated for each object (fish).

5. Experiments

The functionality of the proposed sonar system was verified by carrying out several experimental tests.

5.1 1-meter bucket test

The proposed sonar system was tested using a 1-meter bucket test. First, two ePWM signals are generated using the OMAP L-138. Second, the two PWMs are given to the custom HV pulse generator as input. The HV pulse generator will first increase the voltage of the signal and then transforms the square shape into sine shape. Figure 17 shows the pulse package. Each pulse package contains several pulses. The number of pulses in a pulse package is chosen based on the depth of the ocean. While in shallow waters, less pulses are generated, as a result, less energy is dissipated into water. On the other hand, when is deep ocean (for example 500 meters), each pulse package contains more pulses, so, more energy is dissipated into the ocean.

Below two figures show the HV pulse generator after amplification of the ePWM signals and after transforming the square shape into sine shape, respectively.

The final output of the HV pulse generator while the pulse is zoomed in for clarification is shown in Figure 16.

Figure 16: HV Pulse Generator output after (Pulse Zoomed-In) after transforming the square shape into sine shape

As seen above, the sine is not perfect but good enough to vibrate the transducer. Figure 17 shows three pulse packages. Each pulse package includes several pulses. Depending on the depth of water, timing of pulse generation and silence time is changed. For example, for deeper sea, longer pulse generation and longer silence time is used, when compared to shallow waters.

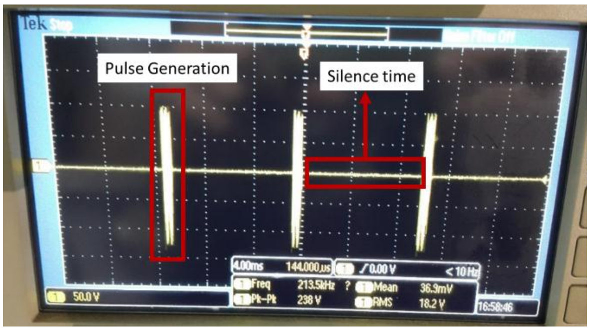
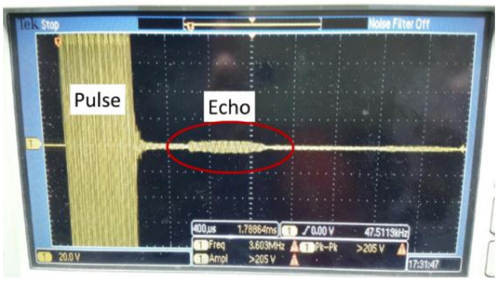


Figure 17: Final HV pulse generator output (pulse package)

Third, the HV sine pulse is transmitted into a bucket full of water with 1-meter height and the echo is captured by the transducer. The below figures show the transducer positioning and the received echo response.

(a)



(b)

Figure 18: 1-meter test: (a) transducer position (b) echo response

In order to convert this analog signal, the high voltage pulse and echo should be given to the AFE5809 as input. Later, AFE5809 can convert this analog into digital signal. However, the pulse has very high voltage (about 200 Volt peak-to-peak). As a result, if this high voltage is given to the AFE5809 directly, it will damage the board permanently. To avoid such damage, the high voltage signal must first be lowered using a T/R Switch (TX810). The T/R Switch reduces the high voltage into low voltage and then this low voltage analog signal is given to AFE5809 as input. The AFE5809 converts the analog signal into digital signal and then the digital data is transferred to the PC using TSW1400. Finally, the results are shown by HSDC Pro software in the PC. Here is a photo of the results.

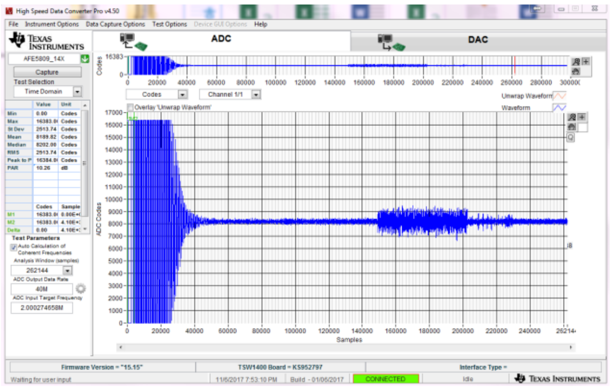


Figure 19: Received echo shown in PC by HSDC Pro software

The Control GUI notifies the Fish Finder GUI about the received signal. So, Fish Finder GUI reads the .CSV file which contains the digital signal data and displays the data in the Fish Finder GUI. The results for this 1-meter bucket test are shown in Figure 20.

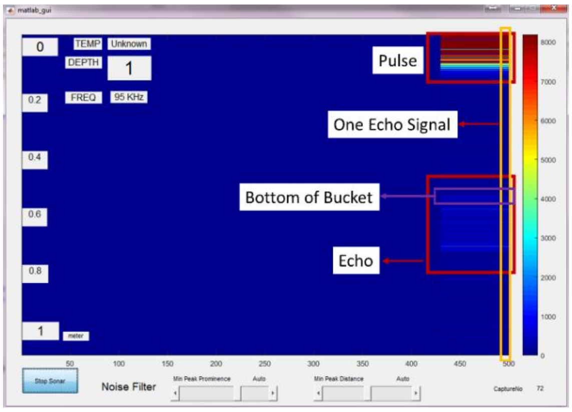


Figure 20: Fish Finder GUI: Showing signal results in colorjet

As shown in figure above, the pulse and echo are shown in color chart. Blue indicates weak signal and red indicates strong signal. The pulse has a strong signal, so it looks completely red while the echo is in light blue.

5.2 10-meter shore test

The prototype was tested beside the shore with a depth ranging from 1 to 10 meters. The below figures show a sample of transmitted pulse package and it's received echo. As shown below, the echo is very weak. The reason is because the transducer requires 300W of energy to work properly, however, our pulse generator, currently, can generate about 40W of energy (100 RMS volts with 0.4 ampere).

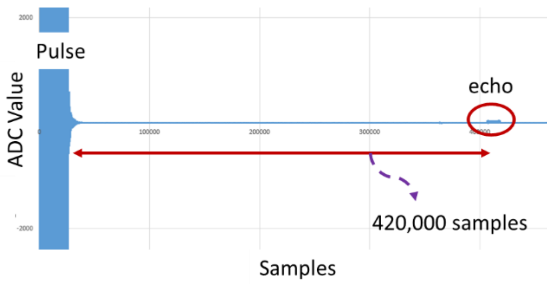


Figure 21: 10-meter shore test echo signal

First, the time (T) traveled by the pulse should be calculated from the samples. The ADC sample rate is 65 MSPS (Mega Sample Per Second). Using this sampling rate, for the data shown in the Figure 21, the time is calculated by equation (1):

$$T = \frac{420{,}000 * 1}{65 * 10^6} = 6.46\, mSec$$

Now, using the calculated time, the distance is calculated by equation (2):

$$D = \frac{V\ x\ T}{2} = \frac{1500 * 6.46 * 10^{-3}}{2} = 4.85\, meter$$

where D is distance to object, V is velocity of wave in water and T is time traveled to reach the object and come back to the transducer.

The calculated distance (4.85 meters) is pretty close to the actual distance (5 meters). This indicates the correct functionality of the prototype.

As show in Figure 21, the echo of this test was weak but still readable. We tested for longer ranges including 10 and 50 meters, however, the echo was very weak and not readable anymore. The reason for this weak echo was because we need much more power to transmit the pulse signal into water. Currently we can produce only about 40W of energy but in order to work optimally, the transducer needs 300W of energy.

6. Conclusion

In this paper, the process to develop a sonar system (fish finder) was explained. The process was divided into two major parts, namely, sonar hardware and sonar software. A prototype of a sonar system, with two sub path circuit, was developed. This prototype was divided into two sub-circuits, namely, Transmit Path Sub-Circuit and Receive Path Sub-Circuit. The necessary software to control and obtain the results of the prototype was also developed. The prototype was tested twice, first, in a 1-meter test, and second, in a 10-meter shore test. The hardware worked as expected and the software captured the data successfully. The data was also shown in a custom GUI similar to a manufacturer fish finder.

6.1 Future direction

The HV pulse generator currently can produce about 40W of energy. This is no sufficient to fully activate the transducer. A new pulse generator with 300W energy should be developed to fully activate the transducer**.** After increasing the pulse power, the prototype should be tested in deep water (over 10 meters).

References

[1] Instruments, T. *SONAR Receiver Path Sub-System Reference Design Using the AFE5809*. Available from: http://www.ti.com/lit/ug/tidu702/tidu702.pdf. 2015 Oct. 2017

[2] Stergiopoulos, S., *Advanced signal processing handbook: theory and implementation for radar, sonar, and medical imaging real time systems*. CRC press. 2000

[3] Sherfey III, S.R., *A mobile robot sonar system*, NAVAL POSTGRADUATE SCHOOL MONTEREY CA. 1991

[4] Lochner, J.T., *Analysis and Improvement of an Ultrasonic Sonar System on an Autonomous Mobile Robot*, NAVAL POSTGRADUATE SCHOOL MONTEREY CA. 1994

[5] Kelly, I. and D. Keating. *Flocking by the fusion of sonar and active infrared sensors on physical autonomous mobile robots*. in *Proceedings of The Third Int. Conf. on Mechatronics and Machine Vision in Practice*. 1996.

[6] Burckhardt, C., P.-A. Grandchamp, and H. Hoffmann, *An experimental 2 MHz synthetic aperture sonar system intended for medical use.* IEEE Transactions on Sonics and Ultrasonics. **21**(1): p. 1-6. 1974

[7] Barshan, B. and R. Kuc, *A bat-like sonar system for obstacle localization.* IEEE Transactions on systems, man, and cybernetics. **22**(4): p. 636-646. 1992

[8] Van Veen, B.D. and K.M. Buckley, *Beamforming: A versatile approach to spatial filtering.* IEEE assp magazine. **5**(2): p. 4-24. 1988

[9] Wong, G.S. and S.m. Zhu, *Speed of sound in seawater as a function of salinity, temperature, and pressure.* the Journal of the Acoustical Society of America. **97**(3): p. 1732-1736. 1995

[10] wikipedia. *Speed of sound*. Available from: https://en.wikipedia.org/wiki/Speed_of_sound#Seawater. 2017 Nov. 2017

[11] Instruments, T. *TX810: 8-Channel, Programmable T/R Switch for Ultrasound*. Available from: http://www.ti.com/lit/ds/symlink/tx810.pdf. 2010 Oct. 2017

[12] Instruments, T. *AFE5809 Fully Integrated, 8-Channel Ultrasound Analog Front End With Passive CW Mixer, and Digital I/Q Demodulator, 0.75 nV/rtHz, 14, 12-Bit, 65 MSPS, 158 mW/CH*. Available from: http://www.ti.com/lit/ds/symlink/afe5809.pdf. 2015 Oct. 2017

[13] Instruments, T. *TSW140x High Speed Data Capture/Pattern Generator Card*. Available from: http://www.ti.com/lit/ug/slwu079d/slwu079d.pdf. 2016 Oct. 2017

[1] Zed, Yinhai. "A Novel SVPWM Modulation Scheme," in *Applied Power Electronics Conference and Exposition, 2009. APEC 2009. Twenty-Fourth Annual IEEE*, 2009, pp. 128-131.