Simulink Model of Active Sonar System Design using Ultrasonic Piezoelectric Transducer

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***Abstract* – These instructions give you basic guidelines for preparing camera-ready papers for conference proceedings.**

Keywords:

Piezoelectric transducer excitation, sonar system, echo signal processing, underwater acoustics, underwater range calculation

I. Introduction

Ultrasonic technology has been prevailing since decades **(tong, figueroa)**. The use of ultrasonic technology has multiple applications including ultrasonic distance measurement systems, SONAR (abbreviation) etc. The source of inspiration for the development of sonar technology has been derived from nature by imitating the navigation system of bats, dolphins and whales etc. **(Kaveh, Farhoudi)** using ultrasonic sound waves. This is known as echolocation as was first coined by Griffin **(Kaveh, Farhoudi - 18)**. Requirement of precision in distance measurement has been a crying need in numerous applications of science and technology. The need for precision in determining geometric distances led to the design and development of active ultrasonic transducers to utilize the properties of sound for such application **(Lee, Huang…)** like underwater perception, on air distance measurement etc.

The working mechanism of active ultrasonic transducers require continuous transducer excitation to transmit sound waves at ultrasonic ranges. In order to excite these transducers, the power supply has to be applied maintaining certain transducer specifications. The requirement of precise power at defined frequency is essential to avoid power loss and obtain optimum competences. The transmission of signals at resonant frequency depending on the characteristics of each transducer is thus necessary. The transducer parameters maintain versatility and every system is to be designed according to its own specifications. Therefore, all available transducers in the market needs to have its own specified module to excite and receive the transmitted signals as echo. As mentioned by Wang & Tsai **(Wang, Tsai)**, transducers can be dynamically modelled using constitutive electrical and mechanical equations to study and analyze its responses. These equations could be employed to understand, characterize and simulate the behavior of transducers for determining the requirements to design modules.

As transducers can be modelled using resistors and capacitors **(Lester W. Schmerr Jr. [Fundamentals of Ultrasonic Non-destructive Evaluation pp 1-13])**, the primary conditions for transducer excitation are power and frequency matching through RLC networks **(Yang, Wei, Zhang and Yao)**. Once, the power and frequency are matched according to the transducer impedance following the maximum power transfer theorem, the transducer will transmit bursts of ultrasonic waves. These waves will then generate reflected waves or echoes when they are obstructed. The echo will evidently have to be perceived so that the measurement of distance could be determined from the time of flight [TOF] **(Lee, Huang…)** and the speed of sound in the medium using speed-distance equations. However, the echo received are usually contaminated by noises from the environment. This signal requires refining through filters so that only the echo can be detected from the environment.

Under such circumstances, the paper proposes a module design for 200 KHz active ultrasonic transducers by modelling the transducer through its parametric calculation and then defining the module to excite and receive echoes respectively. Though the 200 KHz frequency has been chosen arbitrarily, a reason behind the high range frequency is because generic 40 KHz transducer modules are already available in the market such as the microcontroller compatible HC SR-04 and JSN SR-04T but such high power and high frequency transducer signal processing modules are less likely available. These high range transducers could be used for long range perception in air and water. The long-range sensing transducer in this particular paper will be targeted for underwater use because most of the underwater sensors are large in size and less cost effective. Moreover, they are mostly military grade and not used for general purpose. Further, piezoelectric PZT – 4 has been chosen as the transducer material for analysis because of its significant coupling factor as appropriate for high acoustic drive. Additionally, they are highly resistant to depolarization and dielectric losses are minimized when high power driven.

As very limited amount of resources is available for these type of transducers, the paper will bring a better impact through its proposed design. Among a few mentionable work in this field, **(Wang and Tsai)** developed transducer model using block diagram approach to develop dynamic model of thickness-mode piezoelectric transducer. They used their model to characterize the parameters for modelling and analyzing the behavior of piezoelectric transducers. On the context of methodological algorithm, **(Guarato, Laudan and Windmill)** worked on target localization using active sonar. In their system, they defined localized target by intersecting four ellipsoids between one emitter and four receivers and calculated the time of flight in air. They focused on the localization principle and defined the system in a laboratory environment. Their emphasis was autonomous system development. Further, **(Luo, Han and Fan)** developed a review on tracking targets using ultrasonic acoustics. In their effort, they developed their literature on the basis of various algorithms that used tracking methods to trace targets. Additionally, **(Kuang, Jin, Cochran, Huang)** have developed a driving and measuring system to track the high-power transducer resonance and vibration velocity to stabilize the transducer for optimum capabilities. They made the system capable for monitoring the operating and performance parameters of transducer in real time using their control algorithms and simulated the system in LabVIEW. This added to versatile use as the system could be implemented in a flexible manner on various modes of transducers. Furthermore, **(Yang, Wei, Zhang and Yao)** in their paper labored on sandwiched piezoelectric ultrasonic transducer's electrical impedance matching on electromechanical behaviors. They emphasized on 2 types of impedance matching network models namely type I and II. These were series and parallel combinations of capacitance and inductance to model the electrical impedance matching network and they imitated the simulations on PSpice to analyze the time and frequency domain behaviors and hereby characterize the responses of the resonance and anti-resonance frequencies. This paper has used impedance matching using similar methodologies. Then again, **(Josserand and Wolley)** designed a miniature high-resolution sonar imager using the frequency steered phased array technology. Their system devoid of high power, complex circuitry and processing units and consisted of large numbers of beams in the form of array to perceive the signals. Though the method presented a high-resolution image, the distance covered by the system was lower in comparison to the expectations of this paper. Thus, the paper proposes a designed system that would fill in the necessity of a module for high power, high frequency ultrasonic underwater transducers at 200 KHz.

II. Transducer Selection

Table.1
Selected Transducer Specifications

Transducer parameter	***Value***
Resonant frequency (f_r)	200KHz ± 4KHz
Material construction	PZT-4 (enclosed type)
Rated Power(P_{rated})	50W
Beam angle (θ)	14.1°
Switching frequency (f_s)	201.024 *kHz*
Receive Sensitivity	−190dB

A typical commercial transducer specification is depicted in table 1. On the basis of the key parameters enlisted, Simulink model of active sonar system would be designed. Long range sonar generally uses enclosed type transducer which outer peripheral is completely sealed. Majority of piezoelectric crystal are manufactured from PZT (Lead Zirconate Titanate) materials. There are several classes of PZT's available **[8]**, each materials having different physical characteristics and are subjected to different applications. PZT-4 have significant coupling factor and is appropriate for high acoustic drive (50 W).Additionally, it is highly resistant to depolarization and dielectric losses is minimum when driven by high power drive. Resonant frequency chosen is $200\,KHz$ having a bandwidth of $BW = 8\,KHz$. Piezoelectric transducer commonly uses $40\,KHz$, $200\,KHz$, $500kHz$ frequency crystal. High frequency transducers are for ranging high resolution underwater information. Despite the fact that high frequency gives precise echo ranging data, it is a trade off with maximum distance coverage. Transmitted pulse from transducer tends to attenuate at a greater rate, for high frequency shorter pulse than low frequency wider pulse width. BW of $8\,KHz$ is a narrow bandwidth which in contrast to wide bandwidth have less reverberations and shorter blanking distance. Beam angle of selected transducer is 14.1°, which is considerably a narrow beam width. Narrow beam acoustic signal provides greater directivity but has less angular coverage. Rated power of the transducer is 50W; an input power closer to the rated value is designed in power drive stage. Transducer having higher P_{rated} has longer detection range and would eventually ensure stronger echo return.

III. Transmitter Unit

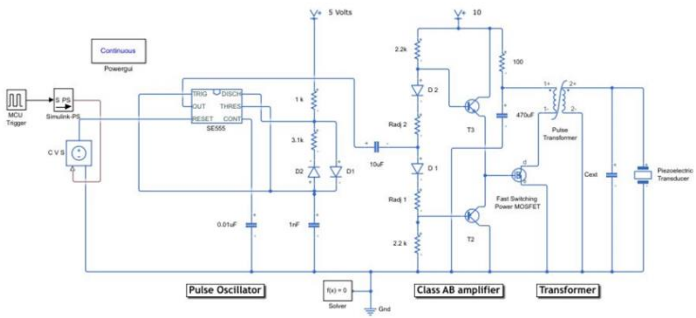

Figure 1: Transmitter Unit Schematics

III.a Pulse Oscillator

Pulse oscillator generates pulse wave at a frequency f_{drive} which is equal to the resonance frequency (f_r), to harvest optimum crystal vibration. Astable multivibrator using a class of 555 timer, SE555 IC would be used to generate pulse signal. This transmission of pulse is controlled by MCU which switches timer on or off to allow/hinder pulse excitation. Simulink design of this module is realized into two separate units as shown in **fig.1**. First unit, 'MCU Trigger' controls number of cyclic pulse generated by timer in each burst. From the virtual oscilloscope output in **fig.2**, region A is the ON-period when MCU signals logic '1'. Width of this ON-period is directly proportional to the scope of information could be hold by return echo. At this instant active burst are generated continuously by 555 timer. Pulse width of this period could be estimated to configure a number of pulses to be generated in each burst.
Let, n be the number of cyclic pulses generated in each burst, the ON–period can be calculated by Eq. 1.

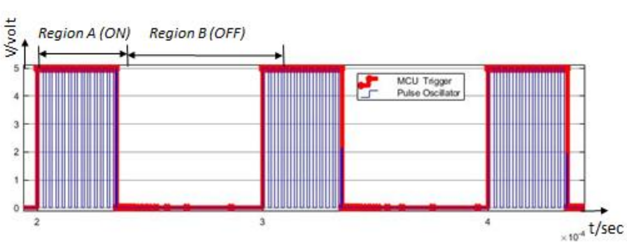

Figure2: Pulse Oscillator output waveform

$$TH_{MCU} = n \times \frac{1}{f_r} \qquad \textbf{(1)}$$

where TH_{MCU} is the ON-period duration.

It's better to fix 'n' and then calculate TH_{MCU}, standard value of $n = 8, 20, 40$ ....
Considering $n = 20$, from Eq. 1 $TH_{MCU} = 100\mu sec$,which infers, to generate 20 cyclic pulses at single instant MCU must hold the logic level '1' for around $100\mu sec$.

Second unit, is the generic astable multivibrator which continuously generates frequency at 200 kHz until TH_{MCU} goes down to logic 0. Transducer is in active transmission or non-listening mode (fig. region A) , when TH_{MCU} is 'high' .In practice, piezoelectric transducer has an unfavorable characteristics known as ringing. This brings about the extension of transmission period in excess of TH_{MCU}.

$T_{burst\_duration} = TH_{MCU} + T_{ringing}$, where, $T_{ringing}$ is the excess time due to ringing. If this duration can be minimized transducer efficiency could be improved.

Region B is the listening (OFF- period), at this instant transducer listens for echo and hence no transmission takes place. Transducer is completely isolated from the Tx unit, to prevent needless power loss and burst generation.

From the second unit of pulse oscillator circuit following pre-design consideration is employed:

$$R_B \gg R_A\ ,\quad C_1 = 1nF, R_A = 1k\Omega,\ C_2 = 0.01\mu F.$$

The equations below were used to calculate values of R_A and D.

$$T_H = (ln2)\ (R_A + R_B)C_1 \qquad \textbf{(2)}$$
$$T_L = (ln2)\ R_B C \qquad \textbf{(3)}$$

where, T_H corresponds to logic '1' and T_L corresponds to logic '0', of cyclic pulse generated by the timer.

$$f_{drive} = \frac{1}{T} = \frac{1}{T_H+T_L} = \frac{1.44}{C_1(R_A+R_B)} \qquad \textbf{(4)}$$
$$= 200\text{ kHz}$$

$$\text{Duty cycle, } D = \frac{R_A+R_B}{R_A+2R_B} = 56.9\% \qquad \textbf{(5)}$$

III.b Power Drive

High voltage signal excitation is required to drive the transducer to maximize mechanical vibration which produces an acoustic sound wave. Driven power must be closer to the rated power of the transducer (P_{rated} = 50W). Our focus of this stage is to design a circuit module which would excite transducer to yield greater range and ensure significant echo return. Generally, two ways of excitation are available **[9]:** a) Transformer Drive (for enclosed type transducer), b) Power Mosfet Drive (for open type transducer).

High powered and enclosed type transducer requires using transformer for excitation. Use of High voltage Mosfet drive would be inconvenient to boost power to a level close to P_{rated} . Even though Power of 50W maximum rating might not seem of a significant value and cascading conventional amplifier might appear to serve the purpose. But, the reason behind the use of transformer is it places itself as best candidate to provide dual function simultaneously. In sonar system design, it could be used to step up voltage as well as its turn's ratio could be adjusted to match the impedance of transducer. In practical applications for e.g. higher depth ultrasonic transducers used in ocean ranging might need to be excited at several 'kW', alternate other than transformer is vaguely there.
Pulse oscillator output voltage of '5V' and low output current, is incapable of exciting primary side of the transformer. Therefore a linear power amplifier (LPA) would be used to trigger voltage and control I_p (primary winding current). Class AB a LPA type amplifier was chosen for our circuit design. Compared to other LPA's it has low cross-over distortion and is more efficient. In **fig.1** class AB unit, diodes D1,D2 and transistors T1 and T2 are matching pairs. If these components are non-identical cross-over distortion could be reflected in V_{amp}, voltage waveform. Power drive stage is segmented into two distinctive parts, Class AB amplifier and Pulse transformer units. A fast switching power Mosfet **(model:)** as shown in **fig.1** was used to withstand large current at primary winding of transformer.

Transducer needs to be excited at 50W and 200 kHz frequency. We need to consider both the desired frequency and voltage value needs to be supplied by the Tx unit. Signal output from Pulse oscillator is in pulse waveform at 200 khz and 50% duty cycle, when transducer is in transmission mode. Selection on the basis of requirement, high frequency pulse transformer would be used to evaluate design parameters. High frequency transformers have few advantages in material construction **[10]** **[11]**:
a) as the frequency increases the transformer shrinks in size
b) less Cu wire required which reduces Cu loss
c) different geometric construction available.

Despite of having upper hands over low frequency transformer in some aspects, HF transformer brings about few drawbacks. The skin effect and proximity effect are the major challenges which need additional consideration in practical design of pulse transformer. Skin effect results due to high frequency current streaming around the conductor**.** Litz wire are the common wire strands used to minimize this effect and reduce high frequency Cu loss as much as possible. This typical wire is twisted enabling current to distribute evenly, which is how skin effect can be further reduced. Latter effect, the proximity effect are eddy current losses, which are mainly due to magnetic fields induced by nearby conductors. Several practical design techniques described in **[10]**, can be followed in order to implement more efficient HF pulse transformer.

Table.2
Model Parameters of Pulse Transformer

Parameters	Value
Ferrite materials	3E5
Ferrite type	MnZn
Core cross sectional area (A_e)	13.8 mm^2
Peak flux density (B_m)	3800 Gauss
Switching frequency (f_s)	201.024khz
Core shape	Toroid

Ferrite types and materials are application specific, mostly selected on the basis of high permeability ($\mu_{I=}10000$), minimum loss factor and large B_m value. Array of ferrite material grade and their specifications are listed in component notes **[12].**

Transformer parameters used in Simulink circuitry are evaluated from equations given below:

$$L_s = \frac{1}{C_o \times (2\pi f_s)^2} \quad \textbf{(6)}$$

$$P_{rated} = \frac{{E_s}^2}{R_1} \quad \textbf{(7)}$$

$$P_{rated} = E_s \times I_s \quad \textbf{(8)}$$

Using value of C_o & R1 from Table.1, $L_s =$ 0.196mH, $E_s = 132.93V$ and $I_s = 0.376A$.

$$N_p = \frac{E_p \times 10^8}{k A_e B_m f_s} \text{ [10]} \quad \textbf{(9)}$$

$$N_s = n \times N_p \quad \textbf{(10)}$$

$$n = \frac{E_s}{E_p} \quad \textbf{(11)}$$

$$\frac{L_S}{L_P} = \left(\frac{N_S}{N_P}\right)^2 \quad \textbf{(12)}$$

$$\frac{I_S}{I_P} = \frac{1}{n} \tag{13}$$

From Eq.(4-7), N_p= 5 turns, $N_s = 135\, turns,\ n = 27,\ I_p = 10.152A$.

Class AB amplifier can be adjusted to control current flow. But the drive current might exceed rated current of primary and secondary windings, due to transducer features e.g. ringing. To avoid this external capacitor C_{ext} could be connected to absorb excess charge. It is however better to remain in slight capacitive region (phase angle shy of 0°) of impedance response in **fig.4**.

III.c Impedance Matching

Driving voltage V_{drive} delivered by the power drive circuit to the piezoelectric transducer results in electro acoustic conversion. This triggers mechanical vibration of the crystal, which is in correspondence to V_{drive} and its frequency. Response reaches optimum level when the natural frequency of piezoelectric material matches with the driving frequency f_{drive}. . That particular frequency is termed as resonance frequency f_r. Transducer has resonant frequency which is function of material composition and mechanical dimension. The purpose of impedance matching unit is to drive the transducer to work at f_r. Naturally, transducers are capacitive and have high input impedance compared to output impedance of power drive. Due to this high acoustic impedance mismatch between transducer and power drive $Z_{out}(Power\ drive) \ll Z_{in}\,(Piezoelectric\ crystal)$, huge energy would be wasted and transmission efficiency would decline rapidly. To attain efficient transmission the capacitive effect of transducer must be resonated out. This is achieved by exciting transducer to vibrate at f_r, frequency at which the efficiency of electroacoustic conversion shows maximum response.

Several impedance matching techniques are available, two common ways are explained below :

a) Simplest of method is to add external inductor by trial and error methods **[13]** until the overall impedance of transducer is purely resistive. It might facilitate simplicity, but requires several iteration which is unfeasible in practical case. Moreover for high powered transducer e.g. Tonpilz this technique is inconvenient.
b) More rational approach is to use transformer for both power drive and impedance matching units. Turns ratio of secondary coil could be adjusted into equivalent inductance value, to make transducer purely resistive. In our active sonar system design this method was used, to create simulation of power drive as well as to impedance match transducer. This process compensates for imaginary component of the impedance not the real part. A proposed methodology has been analyzed in this paper **[14],** where both imaginary and real part could be matched. We restrict out paper to resonate imaginary component and use approximation method by adjusting N_s (secondary turn ratio) until maximum power could be obtained.

Piezoelectric transducer can be modeled as mechanical portion and electrical portion. Both the individual portion can be compounded into BVD (Butterworth-Van-Dyke model). This model would be used to formulate expression for input impedance of transducer seen by the transformer. BVD model parameters have been inserted in **fig. 3**, for selected transducer. The branch parameters R1, L1 and C1 depicts mechanical portion and Co is electrical portion modeled by BVD. The overall impedance *Z(s)* of this model is capacitive for parameters shown in Fig.1. Simplified general equation of input impedance *Z(s)* is given in Eq. (1).

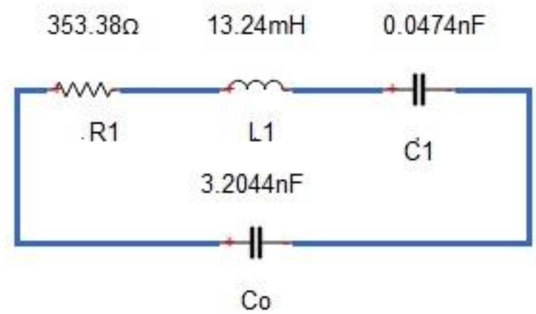

Fig.3: BVD model of Piezoelectric Transducer

$$Z(s) = \frac{s^2 L_1 C_1 + sR_1 C_1 + 1}{s^3 L_1 C_1 C_O + s^2 R_1 C_1 C_O + sC_O + sC_1} \tag{14}$$

After plugging the value of the parameters in Eq. (1), Z(s) can be further simplified to Eq. (2).

$$Z(s) = \frac{(6.27\times10^{-13})s^2 + (1.67\times10^{-8})s + 1}{(2.01\times10^{-21})s^3 + (5.36\times10^{-17})s^2 + (3.25\times10^{-9})s} \tag{15}$$

$$fr = \frac{1}{2\pi\sqrt{L_1 C_1}} = 201.02\ kHz \tag{16}$$

$$fa = \frac{1}{2\pi\sqrt{\frac{L_1 CoC_1}{C_1 + C_O}}} = 202.50\ kHz \tag{17}$$

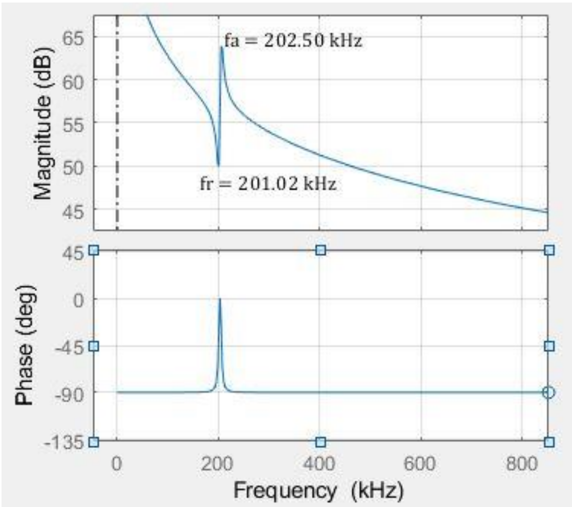

Fig.4: Impedance matching response
(after matching)

From impedance magnitude response graph **fig.4**, there are two distinctive boundary points that marks the range for the dB plot. Frequency, at which the magnitude of impedance is minimal, is the lower cut-off point f_r. Peak impedance magnitude value occurs at higher cut-off frequency termed as anti-resonant frequency, f_a. Electroacoustic conversion takes place from electrical to mechanical power and vice versa. For efficient transmission tra,nsducer must be operated near about f_r and for receiving echo operation is optimum at $f_{a.}$ Phase plot of impedance response depicts characteristics nature of a piezoelectric crystal. Initially, before impedance matching transducer acts like a capacitor. If drive voltage V_{drive} is applied than current **I** would lead voltage **V,** as the phase angle resides in negative degrees. After impedance matching this phase angle reaches close to '0 degree', i.e. **I** is in phase with **V**. It could be attained by addition of inductance value to cancel out reactance produced due to the capacitive effect **[3]**.

IV. Receiver Unit

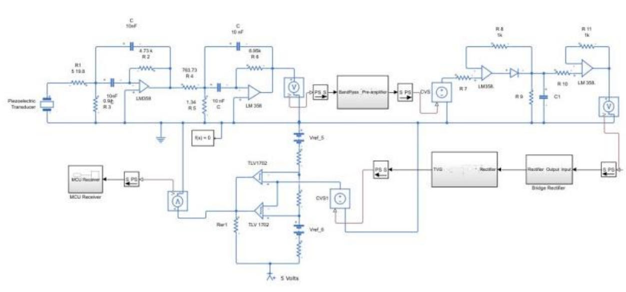

Fig.5: Receiver unit schematic

Transmitted signals are reflected if there lies an impedance mismatch between acoustic boundaries. The strength of reflected signal is directly proportional to the difference of the impedance between acoustic medium. At the acoustic boundary fraction of signal would be transmitted and a fraction would be reflected. Echo signal is the reflected signal at the acoustic boundary. It contains trait of target object, its structural and physical properties are encoded in it. Signal energy flow of which can be modeled by the active sonar equation in Eq.18. It aggregates the general principle guiding underwater medium, additive noise, reflecting object trait and other underlying sonar characteristics. Later electroacoustic conversion takes place at the receiving phase when the acoustic signal is converted to electric signal by the transducer. Efficiency of this conversion is dependent on Receive sensitivity (-190dB).

$SL - 2TL + TS + GS + GT - NL = DT$ **[1]** **(18)**
Active Sonar Equation.

An arbitrary echo signal is formed by amplitude modulation of a 200kHz carrier wave and adding Gaussian noise to the modulated signal. This waveform **fig: 6** is fed into the input of the Rx unit, only the echo detector and comparator circuit design parameter would depend on this signal at the Rx stage.

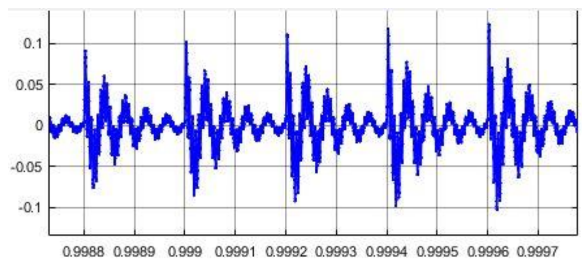

Figure.6: Echo +AWGN

IV.a BandPass Filter

The bandpass filter is the initial stage of receiving unit. It matches filter response with the center frequency f_c or resonant frequency f_r of the transducer. Strongest signal lies at around the f_c, band pass filter ensures to pass echo signal received which are in certain band limit of f_c. This aids in to improve SNR, by blocking weaker echoes which are out of range of BW. Output of BP filter leaves only interested signal to be amplified at first amplification stage, the fixed gain Preamplifier **[15]**. In addition to intensifying signal strength, additive noises due to reverberation are also filtered out. High SNR and precise ranging information can be obtained in the process. Selection of type of band pass filter is important. Order of filter was chosen as 4th order for optimum filter response. Butterworth active band pass filter using MFG topology would be used for our filter design. This typical filter was chosen as it provides better pulse response and hinders signal attenuation more efficiently than other types .The circuitry parameters R, C values would be determined from f_c or f_m and bandwidth of selected transducer. Bandwidth of filter must nearly match that of the transducer. If we chose design parameters which yields too small 'BW', than original information might be lost. On the other hand, larger 'BW' would open the doorway to ambient noise from under water to coalesce with the echo signal. The design parameters have been evaluated and derived from the following equations **[16] :**

$$\alpha^2 + \left[\frac{\alpha.\omega.a_1}{b_1(1+\alpha^2)}\right]^2 + \frac{1}{\alpha^2} - \left[\frac{\omega^2}{b_1}\right] = \quad (19)$$

Where, $\omega = \frac{BW}{fc}$ = 0.04 and the constant terms a_1 and b_1 are $\sqrt{2}$ and 1 respectively. Substituting the values in Eq. (1) and simplifying, characteristic polynomial equation obtained is shown below:

$$\alpha^8 + 4\alpha^7 + 5.99\alpha^6 + 3.99\alpha^5 - 7.6\alpha^4 + 3.99\alpha^3 + 5.99\alpha^2 + 4\alpha + 1 = 0 \quad (20)$$

Solving Eq.(20) the real root of α was found to be +0.825. Mid frequencies of partial filter $fm_1 = fc/\alpha$ and $fm_2 = \alpha fc$ are calculated as 242.4kHz and 165khz respectively. These frequencies are necessary to evaluate values of passive components R, C of the circuit. The other parameters of filter evaluated are:

Pole quality of partial filter Q_i = 36.01
Individual gain of partial filter Am_i = 4.55V/V.
The design values calculated from parameters above are shown in band pass stage in **fig .5.** Overall transfer function of generic 4th order Butterworth band pass filter is shown in Eq. (21).

$$A(s) = \frac{\left(\frac{Am\omega^2}{b_1}\right)s^2}{1+\left(\left(\frac{a_1}{b_1}\right)\omega\right)s+\left(2+\left(\frac{\omega^2}{b_1}\right)\right)s^2+\left(\left(\frac{a_1}{b_1}\right)\omega\right)s^3+s^4} \quad (21)$$

Echo signal amplification begins after band pass, in order to avoid additive noise to amplify conjointly. Hence, mid frequency gain $A_m$is considered to be unity. Plugging all the obtained constant terms in Eq. (21), the required transfer function for our circuit is shown in Eq. (22).

$$A(s) = \frac{0.0016s^2}{s^4+0.0566s^3+2.002s^2+0.0566s+1} \quad (22)$$

First stage of amplification is done immediately after the BP filter. The signal strength of echo highly depends on type of application and transducer used in active sonar system. The range of echo lies in around mV voltage level. It might further decrease if attenuation factor is significantly large. The fixed value of this gain can be set, if the transducer sensitivities are known. Acoustic sound wave exerts force on particles in a material medium, acting upon a specific dimension, which is termed as SPL (sound pressure level). It determines transducer sensitivity, which is inclined to the quality of electro-acoustic conversion. Manufacturer of transducer usually provides with the launch and receive sensitivity based on the construction of piezo-electric material. SPL can be defined as shown in Eq. (23).

$$\text{SPL} = \frac{Ps}{Pref} \quad (23)$$

where Ps is the source pressure and Pref is the reference pressure, oftentimes taken as 1µPa, 1µbar and 0.0002µbar **[17]**.

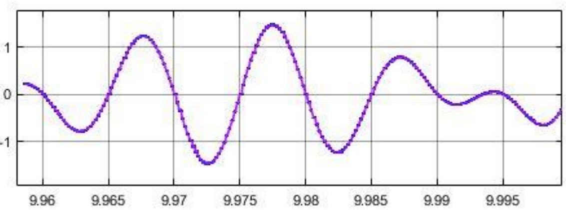

Figure.7: Echo after fixed gain amplifier

IV.b Echo detector

The band passed echo is passed into a full wave rectifier circuit. Rectified signal is then processed to detect the maximum amplitude value at the peak detector circuit. Since positive echoes were ensured at the initial stage by rectifier. Positive peak detector with only a forward bias diode will serve our purpose. Echoes are generally of weaker strength and fall in 'mV' voltage level range. This magnitude minifies as the tested range increases and received echo is highly attenuated. Before proceeding into echo detector circuit design, these factors need to be considered. Components of this module need to be adjusted according to received signal amplitude. At the first stage, during positive half cycle diode **'D'** is forward biased which charges Capacitor **'C'** to its peak value. During negative half cycle output of capacitor Vc> Vout, which makes diode **D** reverse biased. The output terminal is isolated from the input, which brings about capacitor role to discharge through resistor **'R3'**. The rate of which is determined by the discharge time constant. Duration of it is solely determined by the value of **'C'** and '**R3**'. Next stage of the circuit, a voltage follower has been used; it hinders any undesirable discharge of capacitor due to loading effect. A feedback resistor of '1KΩ' was required to reduce offset input leakage current .Selection of opamp needs to be precise as maximum voltage level we are dealing with is very low in magnitude. Characteristic opamp having high slew rate needs to be chosen to avoid limiting detector to reach its peak value. Decoding range information will be tougher if the maximum voltage level is clipped off. Post-amplification was done after echo detector stage. A basic non-inverting amplifier can be used to amplify peak detected echo to the desired voltage level. However, this technique is more unpractical as it requires several iterations and adjustment needs to be done for each stage of range calculation. Time varied gain (TVG) can be employed for a specific application which increases dB level with time. TVG makes separate targets of identical size to be appearing as it is, even though they are isolated by large distance. In circuitry, according to the inverse square law of spherical divergence, it varies with time to make up for the proportional decrease in receive signal magnitude. Acoustic beam intensity drops by around 6dB for every distance doubled **[18].** In addition to distance covered echo signal is attenuated due to several loss factors as can be explained by 'Sonar equation' **.**TVG must compensate for this drop by detecting and elevating voltage level in multiple steps.

IV.c Comparator

Echo threshold comparator calibrates acoustic range extending from near-field region to maximum far-field region of targets. Bursts are transmitted and received within this scope only. It prevents power drive to transmit high power burst needlessly out of calibration range and wait for receiving echo which are out of interest. The major purpose of ADC calibration is it saves power as well as improves data rate at which signal could be processed and analyzed by MCU. Initially, the range was estimated from echo detector output, and both the minimum and maximum amplitude values were noted. These extreme values would let us set the lower and upper threshold for the comparator circuit. It can be tuned by adjusting dc reference voltage and variable resistor '**R2'. C**omparator circuit was used to set lower threshold (**VTHL**) and the upper threshold (**VTHH**) voltages **(fig.8)**. The output voltage is high when **VTHH <Vcomp<VTHL** and low out of this limit. Lower DC reference voltage was set to signal out portion of echo signals which have amplitude below **VTHL,** signal probable from the weak object. Higher DC reference voltage was set to filter out echo signals which are above **VTHH,** signal resulting from additive noise. The pulse width of the comparator is proportional to ranging distance. Acoustic information is encoded in the duty cycle of the comparator pulse. Near objects will return stronger echo and intensify larger pulse width. On the contrary, distant objects respond slowly and have shorter pulse width. Analog comparator of this kind works as a 1-bit ADC system, which checks for only two voltage levels VTHH & VTHL. The output of which is in TTL level digital signal that can be easily fed into high-end MCU. Further, based on programmed algorithm, echo signal can be decoded to unfold ranging information about the target. High-resolution sampling could be achieved using multi-bit analysis. Smaller targets can be detected and resolved by increasing 'n' number of bits and the speed of sampling. MCU can be programmed to compare signal strength against sample threshold. Problem with this approach is it gets far more complicated with the increase in 'n' and sampling speed **[20]**.

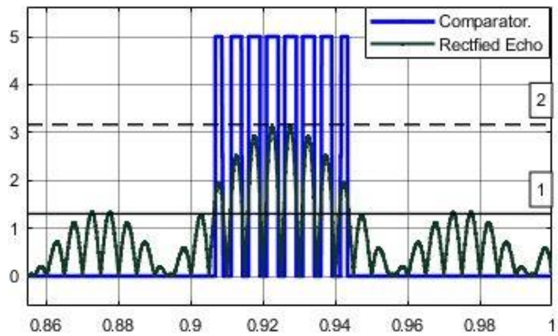

Figure.8: Comparator and rectified Echo

V. Range Calculation

Range from is calculated using TOF method, delays due to circuitry components were not taken into consideration. The difference between negative as positive edges as shown in **fig.9** is our desired TOF. Range is calculated using Eq.(24)

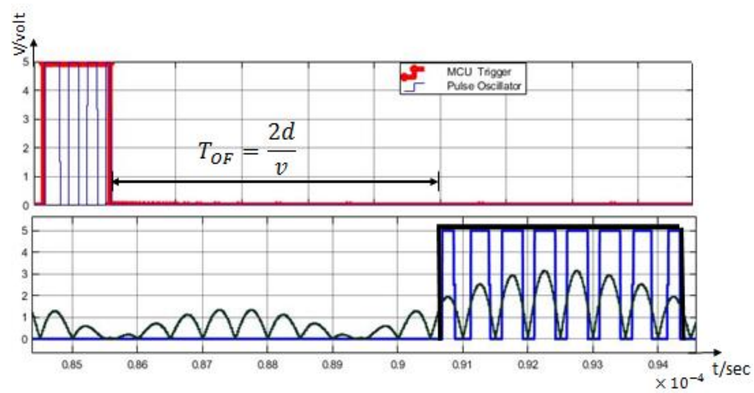

Figure.9: TOF measurement

$$R = \frac{cT_{OF}}{2} \quad \textbf{(24)}$$

where, c is the acoustic speed of the medium. At an instant when multiple echoes are received by the transducer, signal having greatest strength are taken into consideration to calculate R. The other parameter which is of interest is range resolution. It identifies minimum attainable vector distance Rx echoes are isolated from each other and still be resolved into separate echoes. Reflected echo from targets merging in between this distance overlaps and echo detector circuit would not be able to distinct into separate echoes. Evaluation of range resolution of selected transducer is given below; since our transducer emits narrow beam width signal, range is calculated using narrow band equation **[19].**

$$R_{NB} = \frac{c.TH_{MCU}}{2} \quad \textbf{(25)}$$

$$= \frac{1500 \times 100\mu}{2} \quad = \quad 7.5cm$$

VI.Conclusion

In this paper a modular approach to active sonar system design has been presented. This paper is limited to signal waveform analysis and evaluation of circuitry module parameters. The major advantage of this simulation based design is it is aligned with the basic principle of sonar. Several research work are available using different complex software tool that requires complex understanding, purpose of using simulink is to make it widely available and understandable about the signal processing and active sonar system design technique. A software algorithm could be developed to interface it with the electronic module. SDR can be employed to further enhance its functionality; it gives the versatility to implement as many as system functions in software and reconfigure hardware. Hardware could be redesigned and modified using HDL to alter hardware functions.

VII. Reference