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Acoustic Signal Attenuation Determination Technique Traveling Through Obstacles

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Abstract**: *This paper presents a novel technique for calculation of attenuation of acoustic signals in the materials in underwater channel. A laboratory procedure and algorithms have been developed for finding attenuation. In many applications like sonar signal processing acoustic signal attenuation in the dome or in an enclosure are required to be known. Finding the actual attenuation while signal passes through the materials is very useful in calculating the precise power transmitted through the enclosures. The attenuation in materials mainly dependent on type of material, signal frequency and launch angle of the signal. A proper procedure has been presented in this paper.***

Keywords: Attenuation, sonar signals processing, acoustics materials, underwater channel.

I. INTRODUCTION

The knowledge of acoustic signal attenuation through materials is very useful especially where the transmitters are encapsulated in enclosures. There are applications like sonar signal processing, acoustic reflectometry where sensors are required to be protected from the outside environment [1-5]. In such applications the transmitting sensors are placed in protecting enclosures and due to this fact the actual transmitted power from the source and the power emitted from the enclosure may differ. The transmitted power outside the enclosure may increase or decrease depending on the materials used. So, the value of correct attenuation is very useful in designing the overall system.

The next section of the paper describes the experimental setup. The third section describes the procedure and multipath issues. The fourth section describes the calculation method and results. The final section concludes the paper.

II. EXPERIMENTAL SETUP

An experiment to study attenuation of acoustic signal through materials in underwater channel placed in the path of acoustic signal has been carried out. The basic set up used is shown in Fig. 1.

A sinusoidal signal of duration 0.5 ms is generated from the DAQ through MATLAB script written in Lab-VIEW. The duration is kept small enough to avoid multi path signal effects. The gain of amplifier is set at 45 dB. This signal from power amplifier is fed to transmitting hydrophone that is working as projector. The signal from receiving hydrophone is fed to the notebook PC in Lab-VIEW through DAQ and pre-amplifier with gain of 10 dB [6-7].

Transmitting sensor:

For testing of materials from 10 kHz to 100 kHz frequency a projector is required which can work for the entire range of 10 kHz to 100 kHz is needed. The BC 311 projector is selected for the purpose, because this hydrophone is the available projector in the lab which can work over the entire desired frequency range.

Need of filter:

As the signal acquired by the receiving sensor that is also a hydrophone is corrupted with the noise. At frequencies 10 kHz to 15 kHz the signal is more affected by the noise. Band-pass filters with various band-widths were used to recover the signals from the noise. The FIR band-pass filters that have linear range in the desired band are used. The filters also remove the DC component coupled to the DAQ as shown in Fig. 2.

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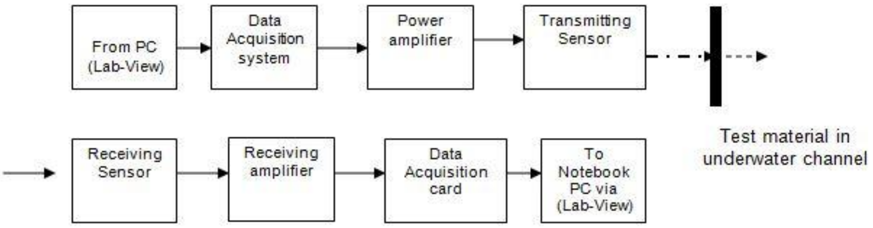

Fig.1: Experimental setup.

III. PROCEDURE AND TACKLING OF MULTIPATH ISSUE

A. Angle calculations for experiments: The entire range of angles between transmitter and receiver used in this experiment to find attenuation are calculated according to Fig. 3. This figure is the top view of hydrophone/projector and obstacle material locations in the tank. The minimum distance between transmitter and receiver is kept 42 cm. The maximum angle between transmitter and receiver is approximately 63 degrees. The angles and distances are summarized in table I.

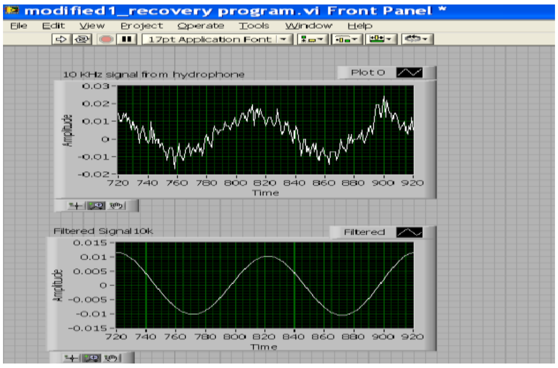

Fig.2: Raw and filtered signal at 20 kHz frequency.

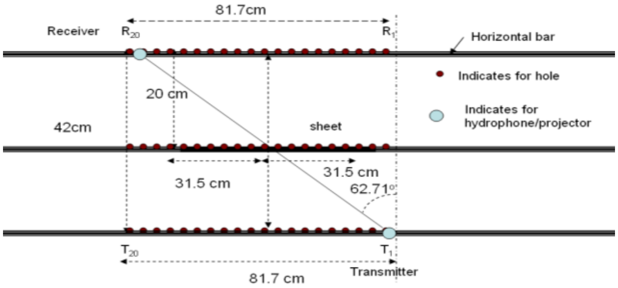

Fig. 3: Calculation of angles and distances between transmitter and receiver (top view).

Table- I: Relative angles between transmitter and receiver

S. No.	Transmitter from Right	Receiver from Right	Displacement between transmitter and receiver	Angles In degrees
1	R_{10}	T_{10}	0	0
2	R_9	T_{11}	8.5	11.5
3	R_8	T_{12}	17	22
4	R_7	T_{13}	25.5	31
5	R_6	T_{14}	34	39

B. Study the multi path structure in underwater channel

The propagation paths of the acoustic signals in the water tank were studied because the water tank present in the lab is a bounded structure unlike the river, lake or sea. The bottom surface is hard and flat where as the side walls are inclined having a slope of 1 in 20. Due to the side walls inclination the sound waves are reflected off the transmitter and are directed towards the surface of the water tank. At the surface, part of acoustic energy is lost due to refraction at the water surface and remaining sound energy is reflected back into the medium. The possible paths for the acoustic waves in the water tank are shown in Fig. 4 [8]:

Direct path: The water temperature in the tank is almost constant throughout the volume. This results in a constant sound speed throughout the tank. This causes a straight-line ray, leaving the source in lines that continue with little or no change in angle until it reaches the receiver hydrophone.

Surface and bottom reflected path: The water in the tank is always stationary as there is no movement in the water tank. As the surface of the perfectly smooth sea can be taken as an almost perfect reflector of sound, the same can be applied to the water tank surface. The reflection loss would be closely equal to zero decibels. The bottom of the water tank is hard and rough and though it reflects the sound energy back into the medium, there is considerable amount of the intensity of the reflected sound beam. The parameters that determine the bottom reflection loss are its density, attenuation coefficient and porosity of the bottom surface. At the bottom of the water tank scattering and absorption of the acoustic energy also takes place. As shown in the Fig. 4, the ray bounces from one surface to other until its energy is dissipated or until it strikes the receiver hydrophone. Similar to light ray, acoustic pulses also have the same angle of reflection and incidence. The reflection from the horizontally flat surface that is from bottom and the water surface are obeying the laws of reflection as shown in the Fig. 4.

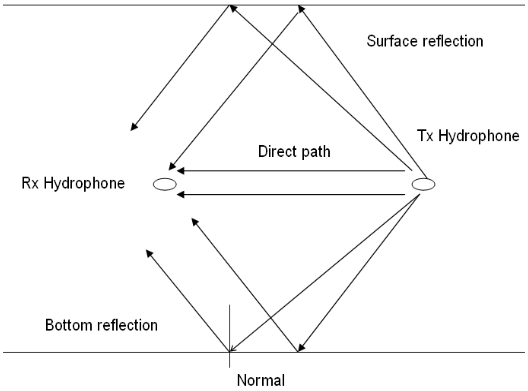

Fig. 4: Direct path and reflection from bottom and surface.

Side walls reflected path: The side walls of the water tank being inclined reflect the acoustic waves in an upward direction.

The side walls also is a hard flat surface so acoustic energy is reflected back in accordance with the laws of reflection. Here as the surface is inclined, the normal to the surface is shifted upward by an angle of approximately 3 degrees, hence the reflected waves are also shifted by the same angle in the upward direction such that the reflection that strike the side wall from a horizontal direction is directed toward the water surface at an angle of 3 degrees.

The comparison of the reflected wave paths with the water tank side walls as inclined and without inclination is shown in Fig. 5 and Fig. 6. It is observed from the figures that if the side walls are not inclined then the acoustic wave striking the side wall perpendicular to it is reflected back in the same direction. But when the side walls are inclined then the same wave is reflected in an upward direction of 3 degrees.

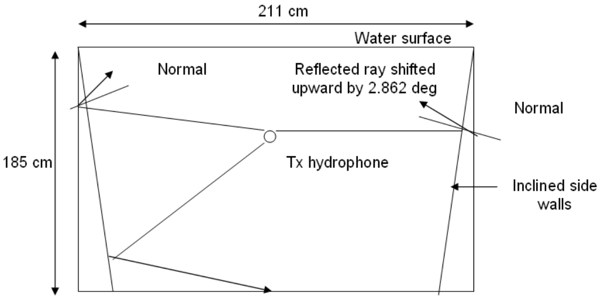

Fig. 5: Effect of inclination of tank side walls.

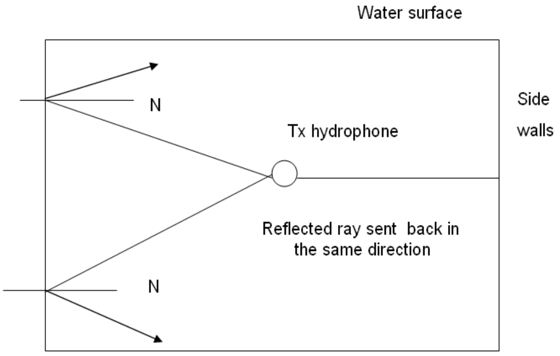

Fig. 6: Effect of flat side walls of underwater tank.

Study of multi path at different transmitting angles: To overcome multi path problem in material calibration, the multi path structure for all position of transmitter and receiver were studied. The transmitter and receiver are placed acoustically at 42 cm distance from each other. At relative angles according to table 2.2 multi path signal strength is studied relative to direct path. The sinusoidal pulse of duration 0.4 ms was finally decided to transmit and receive as shown in Fig. 7 to keep the separation between the direct path and the multi path. From the received wave of duration 1 sec the direct path signal and the indirect path signal were studied. In each position from the received signal, direct path signal magnitude is calculated, and the duration in which indirect or multi path signal magnitude will become less than 10% of direct path is calculated Fig. 7. The worst case observed duration is around 7.5 ms in which the indirect path is only 10% of direct path and it is assumed that at the level indirect signal will not contribute much if the next pulse is transmitted. It is also observed from the received wave form that the multi path will completely die in 30 ms. The result for all angles is tabulated in table II.

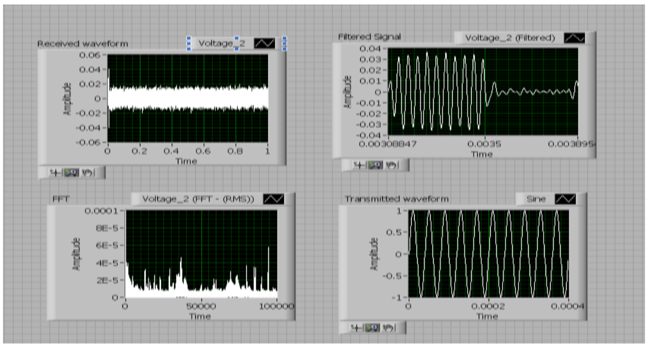

Fig. 7: The direct path and multi path signal separation in filtered signal (right hand side plot)

Table- II: Table of multi path signal duration at various angles between Tx and Rx

S. No.	Relative displacement between transmitter and receiver	Angles between transmitter and receiver in degrees	Time duration in which Ratio of direct path signal to multi path signal is greater than 10
1	0	0	6.1msec
2	8.6	11.57	6.2msec
3	17.2	22.27	6.3msec
4	25.8	31.56	6.4mesc
5	34.4	39.32	6.6msec
6	43	45.67	6.8msec

The side view shown in Fig. 8 gives the detail of exact location of test material, hydrophone and projector in tank. The details of depth of vertical rods along with small vertical rods placed on horizontal bar are also given in Fig. 8.

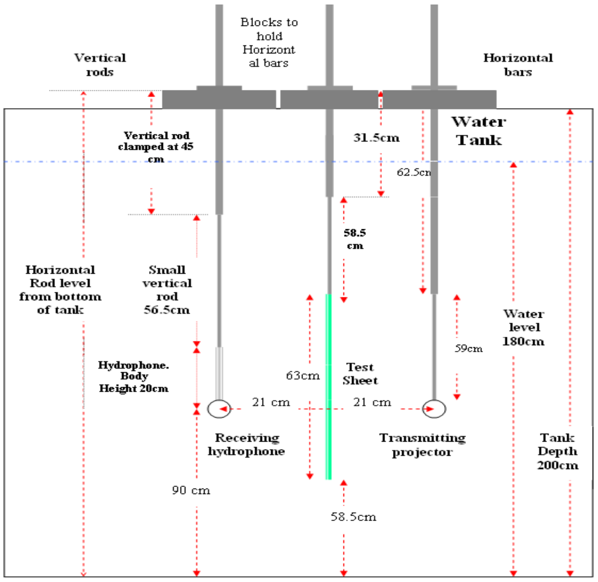

Fig. 8: Side view of sensor placement.

IV. CALCULATION AND RESULTS

A. Calculation of mean and variance of noise:

The noise energy of 25 ms segment duration was calculated and 100 such segments were taken. This is repeated 50 times. Each time mean and variance over 50 segments was calculated. The results are tabulated in table III.

Table- III: Mean and Variance of noise energy over 100 segments of 25 ms.

S.No.	Mean of noise energy	Variance of noise
1	0.2791	8.4738e-6
2	0.2780	4.5423e-6
3	0.2728	7.6491e-6

The experiment was carried out to estimate *SNR* variation due to noise. The *SNR* if noise power is varying can be written as given in (1). The deviation in SNR due to noise power variation is calculated according to (1).

$$SNR = 10 * log_{10}\left(\frac{\bar{Q}}{\bar{P}+\Delta P}\right) \quad (1)$$

ΔP is the standard deviation of noise energy. Here $\bar{Q}$ is the mean signal energy and $\bar{P}$ is the mean noise energy of the measurement. Simplifying (1), we get (2) for *SNR* calculation:

$$SNR = 10 * log_{10}\left(\frac{\bar{Q}}{\bar{P}}\right) + 10 * log_{10}\left(1+\frac{\Delta P}{\bar{P}}\right)^{-1} \quad (2)$$

The mean value of noise energy at each filter output is calculated to find the SNR at filter outputs. For calculating mean noise energy at filter outputs the signal is acquired without transmission and passed through the filters. The 1M noise samples at filter output are taken and their energy is calculated for 100 repetitions. The mean is taken over these repetition values of noise energy for 100 ms. The noise energy is normalized to 0.5 ms duration, that is the duration for which signal is taken, to find SNR.

B. Calculation of attenuation in obstacle materials

To calculate Attenuation *AL* energies with and without obstle sheets are used [9]

$$AL = 10log_{10}\left(\frac{Q_1 \pm \Delta Q_1}{Q_2 \pm \Delta Q_2}\right) \quad (3)$$

Where, Q_1 is the mean value of energies for 250 micro second duration of signal for 25 repetitions with test material in direct path. Q_2 is the mean value of energies for 250 micro second duration of signal for 25 repetitions without material in direct path. ΔQ_1 is the standard deviation of energies of 25 repetitions with material in direct path. ΔQ_2 is the standard deviation of energies of 25 repetitions without material in direct path. Simplifying (3), we will *AL* as given by (4)

$$AL = 10log_{10}\left(\frac{S_1}{S_2}\right) + 10log_{10}\left(1 \pm \frac{\Delta S_1}{S_1}\right) + 10log_{10}\left(1 \pm\right.$$
$$\Delta S2S2 \quad (4)$$

The first term gives the attenuation in the material while the second two terms are the maximum errors in calculation of attenuation.

C. Results of attenuation calculation in plastic material

The amount of attenuation for various launch angles as given in table I are calculated. The results obtained at launch angle of 11.5 degree and 31.5 are shown in Fig. 9 and 10 respectively. The material used for the experiments is the plastic sheet of 5 mm thickness.

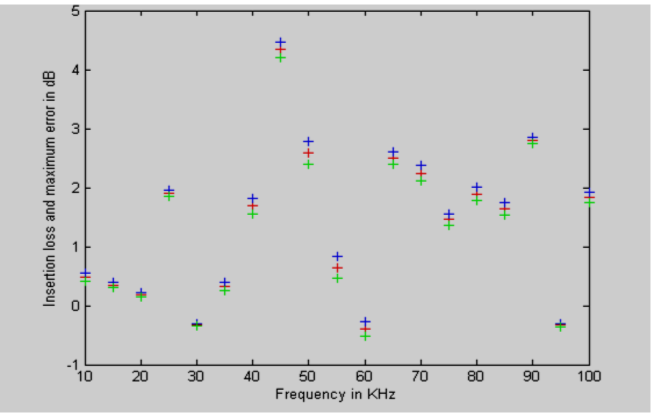

Fig. 9: Attenuation obtained at launch angle of 11.5 degree.

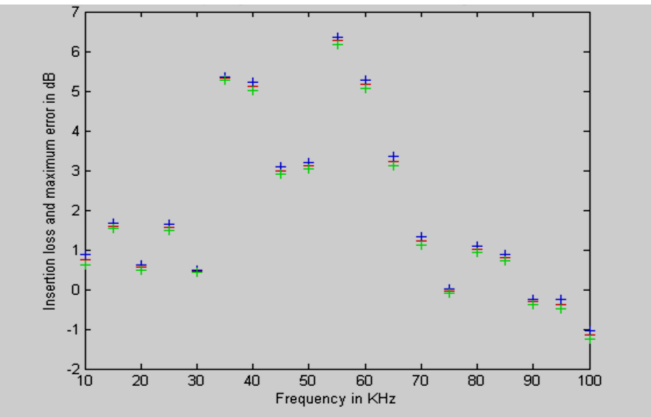

Fig. 10: Attenuation obtained at launch angle of 31.5 degree.

It is observed from Figs. 9 and 10 that at most of the frequencies there is an attenuation varying from 0 dB to 10 dB in the plastic material under test. The Fig. 10 shows that at 100 kHz frequency there is a negative loss. The reason for that is the diffracted signal at high frequencies may reach the receiver from the corners of the sheet.

V. CONCLUSION

The information of acoustic signal attenuation while it passes through a material is very useful in applications where the transmitters are kept in the enclosures to determine the exact amount of transmitted power. A novel method for measuring the losses of acoustic signal while it passes through the materials has been presented in this paper. The negative values of losses have also been observed at certain frequencies and at certain angles. The probable reason for these negative losses is contribution by the diffracted signals from the edges at higher frequencies. To avoid such measurement errors one must take larger dimensions of pieces of material for testing. The main observation is that the losses can also be negative.

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Kapil Dev Tyagi did his BE degree in Electronics and Communication Engineering from Rajasthan University (2003) and M. Tech degree from IIT Delhi(2010). He worked as a lecturer in UP technical university during 2003–2006. He also served as a scientist in Indian Space Research Organization during 2007–2008. He did his PhD degree from IIT Delhi in 2016. Presently, he is working as an assistant professor at Jaypee Institute of Information Technology, Noida.