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Potential of Watch Buzzer as Underwater Navigation Device in Shallow Water Streams

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Abstract: This study aim at developing low cost underwater navigation system suitable for shallow water environment. Spectral Plus 5.0 software running on two computers was used for generating and measuring sound pressure in open air and shallow water (350 mm deep) using a pair of piezocrystals plates (2 cm diameter) from old wristwatch buzzer. The best frequency response was found to be at 4.5 kHz without amplification. The setup was able to respond to obstacles placed in between them when spaced at experimental distance of 30 cm and 60 cm. Obstacles used are plywood, asbestos, PVC plastic and Iron sheet. It was found that the responses are material dependent.

Key words: Buzzer, piezoelectricity, robot navigation, shallow water, sonar, spectral plus

INTRODUCTION

Water is essential to life and our streams, rivers and ocean harbors a lot of resources we need to manage. There are lots of water-based structure like bridges, offshore rigs, port rigs and estuary that needs protection from intruders such as scuba divers and submarines. Furthermore the streams ecological system needs monitoring in a cheap way against pollution of all kind and other hazardous situations.

In robotics, sonar systems are often used for ranging due to their low cost and small size. The signal is sent out continuously or pulsed. The pulsed mode is used for eliminating frequent misreading caused by crosstalk or external sources operating nearby (Tetsuji *et al.*, 2008). Sonar systems have been very attractive for underwater imagery being capable of longer range and are not affected by mucky or muddy water (Dura *et al.*, 2004; Capus *et al.*, 2008). The lower frequency is even effective for longer ranges as depicted in Table 1.

Developing an underwater navigation system is not new but doing it cheaply and safely is a factor universally desired. High power Ultrasonic systems have been known to negatively affect underwater ecosystem (Pierce, 2008; Anonymous, 2002). Also very powerful Low frequency and activated sonar (and mid-frequency sonar) have been claimed to also affect marine life (Jennifer, 2004).

Objective:

- To construct very cheap underwater transmitting/receive system
- To test the system response to various artificial obstacle at audible frequency range as a preliminary work.

Table 1: Sonar frequency and its range

Frequency (kHz)	Range (m)
Low frequency (LF) 8-16	>10000
Medium frequency (MF) 18-36	2000 -3000
High frequency (HF) 30-60	1500
Extra high frequency (EHF) 50-110	<1000
Very high frequency (VHF) 200-300	<100

Justification: Monitoring water systems, waterways, under water structures on continuous bases requires some degree of automation and that cheaply. Small-distributed system will automatically have redundancy in its design and implementation. An example is Passive acoustic observation of finless porpoises by Wang *et al.* (2005). Their system was claimed to be cheap, distributed and automated.

BACKGROUND

Some signal generation techniques (including ultrasonic frequencies): The following methods have been used for generating sound; Piezoelectricity, Electrostriction, Magnetostriction, Cut Quartz, Some plain Mechanical Method. Here is very brief description of each;

A piezoelectric disk generates a voltage when deformed. Naturally occurring materials includes cane sugar, quartz, Rochelle salt, topaz and tourmaline-group minerals (Wikipedia Contributors, 2010a). There is also man made ones like Barium Titanate ($BaTiO_3$), and Lead Titanate ($PbTiO_3$), Lead Zirconate Titanate (the most common piezoelectric ceramic). There are Polymers such as Polyvinylidene Fluoride (PVDF) that exhibit these behaviors too.

Electrostriction is a property of all electrical non-conductors, or dielectrics that causes them to change their

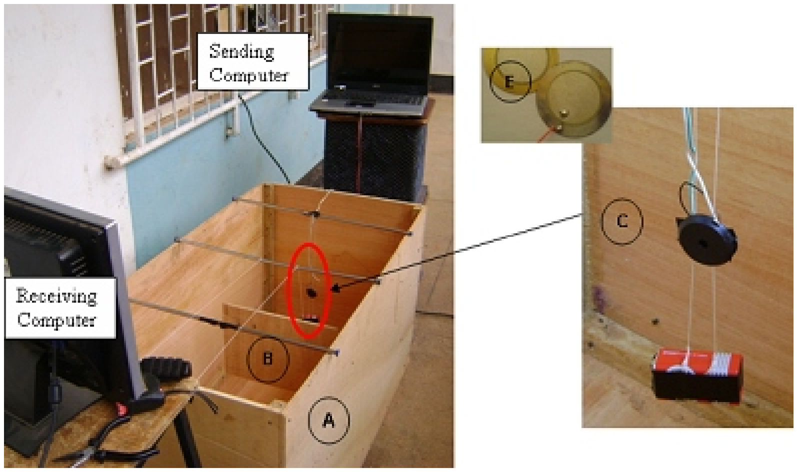

Fig. 1: The experimental setup. The box has not being filled with water in the diagram (A) (B) is a plywood obstacle in place; (C) is the enlarge view of the piezo crystal and the weight (sinker) attached. The crystal is protected. E is the piezo crystal pair for the experiment

shape under the application of an electric field (Wikipedia Contributors, 2010b). Electrostriction is a property of all dielectric materials, and is caused by the presence of randomly-aligned electrical domains within the material. When an electric field is applied to the dielectric, the opposite sides of the domains become differently charged and attract each other, reducing material thickness in the direction of the applied field (and increasing thickness in the orthogonal directions due to Poisson's ratio). The resulting strain (ratio of deformation to the original dimension) is proportional to the square of the polarization. Reversal of the electric field does not reverse the direction of the deformation.

Magnetostriction is a property like Electrostriction but this time around it is the magnetic field that is being responded to by ferromagnetic materials.

Mechanical Method includes the use of tuning fork and whistle.

Under water navigation techniques: Navigating under the water is described as harsh and forbidding (Yuh and West, 2001). Terrestrial instrument used are not always very good for under water navigation. The two common methods in use are (a) Acoustic Transponder with the following characteristics and (b) Dead Reckoning and inertial navigation. The first method involves the use of active or passive sonar of different frequency and power level in continuous or pulsed mode. The later method usually involves magnetic heading sensor and a velocimeter in order to measure the vehicles velocity.

MATERIALS AND METHODS

Environmental condition: This experiment was conducted between February-March, 2009 in the Mechanical Engineering Department Laboratory, Ahmadu Bello University, Zaria, Nigeria. The geographical location is within the Northern Guinea Savannah zone of Nigeria, Latitude 11º 12′N and Longitude 7º 33′E, at an altitude of 610m above sea level. The mean minimum daily temperature is from 14 to 24ºC during the cold season while the mean maximum daily temperature is from 19 to 36ºC during the hot season. The Relative Humidity varies between 19 to 35% during the hot season, and 63 and 80% in the wet season (courtesy of Ahmadu Bello University Weather Station).

Material used: Here is a detail list of material used for this experiment:

- Two Intel based computer system (DELL Latitude cpτ with Celeron 500MHz and and IBM Clone with Intel Pentium 4)
- SpectraPlus 5 Software (Shareware) installed on the two computers
- Two 2 cm back plate old wrist watch buzzer
- Water tank $50\times50\times121 cm^3$ (width, height, length)
- Plain cable (wire)
- Obstacles - Plywood (1/4”) Flat PVC (~1.5 mm), Iron sheet (~1 mm) and Asbestos (~2 mm) thicknesses.

Referring to Fig. 1 one computer (the 500MHz Intel Celeron) is used as the precision frequency transmitter. The output is via audio output (Sound card) of the system. There was no special audio driver between it and the piezocrystal plate. The other computer act as a receiver and its input is through its line-in jack. A stand-alone shelf mounted signal generator was not used to avoid frequency drift and because we want precise control over the frequency being generated, which SpectraPlus 5 is

Table 2: Summary of the peak response with and without obstacles in the air and water

Material used	Relative amplitude (dB) in air		Relative amplitude (dB) in water	
	30 cm	60 cm	30 cm	60 cm
No Object	-71.29	-81.47	-60.16	-57.91
Plywood	-88.95	-90.68	-54.84	-58.05
Asbestos	-83.12	-88.22	-58.36	-58.01
PVC Plastics	-78.95	-81.36	-58.32	-58.03
Iron sheet	-86.17	-89.12	-58.77	-58.18

Table 3: Relative absorption of transmitted power due to water

Material used	Relative absorption at 30 cm apart	Relative absorption at 60 cm apart
No Object	11.13	23.56
Plywood	34.11	32.63
Iron sheet	27.40	30.94
Asbestos	24.76	30.21
PVC Plastics	20.63	23.33

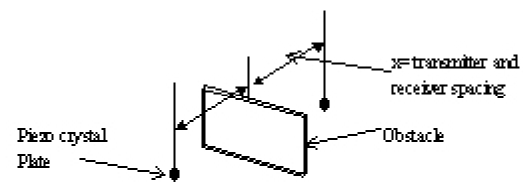

Fig. 2: The arrangement used in the experiment

capable of. Beside that, this software was used to display a spectrum of the frequencies being received, as we desire to have a visual clue to what was going on.

The experiment was started by first finding out the best frequency to use at the stabilized laboratory temperature of 28ºC. The possible frequency available was limited by the hardware (multimedia card) from 0Hz to 22 kHz - the volume was adjusted to maximum. Furthermore, it was also realized that the piezocrystal plates were also designed for audible frequencies range.

The frequency that gave optimum response (no obstacle in between and in the open air) was found to be 4.5 kHz, which is barely audible at maximum volume used. This value also gave best response under the water. We can safely conclude that this is the natural frequency of the crystal plates. With this finding, 4.5 kHz was used in performing the experiments.

Experimental setup: Four categories of experiment were conducted. The obstacles were placed at equidistance between the transmitter and receiver (Fig. 2), follows;

Experiment 1: Obstacle at 30 cm open air
Experiment 2: Obstacle at 30 cm inside water
Experiment 3: Obstacle at 60 cm open air
Experiment 4: Obstacle at 60 cm inside water

The selection of these values is based on our goal of finding out if these piezo crystal plates can be used for obstacle avoidance and possibly for close range navigation of shallow waters.

RESULTS

The results in Table 2 were obtained and are hereby depicted as a screen capture in Fig. 3 to 21. The frequency of interest is the 4.5 kHz. The other frequencies on the spectrum are due to interference from nearby equipments and other factors that shall be explain shortly. A coaxial cable was not used so as to minimize the interferences as it is aimed to reproduce a scenario expected on the field and also to demonstrate what sought of reading/or output to expect. A band pass/ tuned filter network will remove the interferences. Table 3 shows the relative power absorbed due to water arranged in descending order (for the obstacles only).

DISCUSSION

The first observation is that the experiments done in submerged water has a lot of interference or harmonics compared to those in the air. The reason is attributed to boundary layer effect. The reservoir used has a finite boundary with dimension comparable to the distance between the piezocrystal plates. The beauty of these result (under water) is that we have a visual clue to what happens in confined places, for example, an under water robot passing between crevices and using sonar based navigation system will definitely experience this behaviour.

It is also observed that the transmitted frequency (4.5 kHz) still stands out and a band pass filter as earlier mentioned will eliminate the spurious frequency components.

Another observation is that the peak (relative Amplitude in dB) generally increases in water compared to the air based. This is not necessarily so between materials. The reason for this phenomenon is still being investigated. For example, we naturally expect the peak to be greater for sheet metal (as a better sonar transmitter than plywood) but it is not so. One possible reason may be due to thickness difference or the resonance or wave propagation nature of the material especially at the frequency used. Wave attenuation according to Zhao *et al.* (2006), due to material property may be responsible for some of the behavior noted.

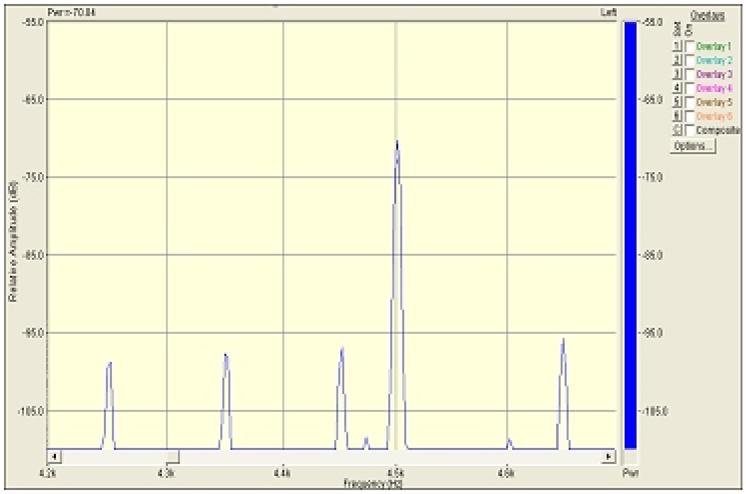

Fig. 3: Spectrum obtained when transmitter and receiver were 30cm apart in air and no object in between

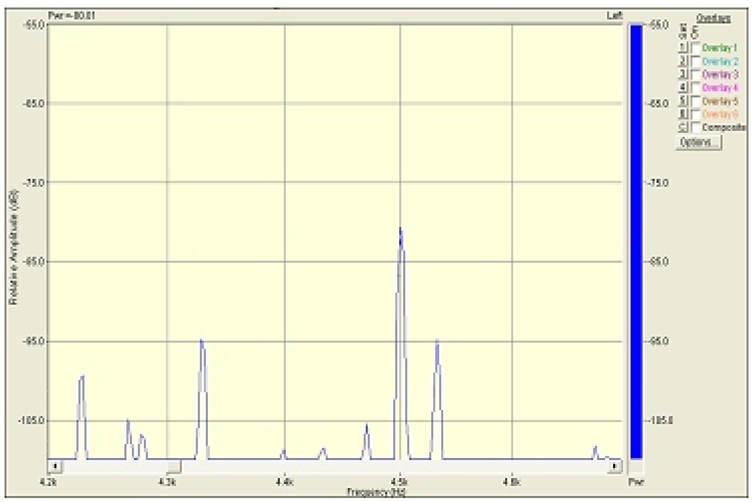

Fig. 4: Spectrum obtained when transmitter and receiver were 60 cm apart in air and no object in between them

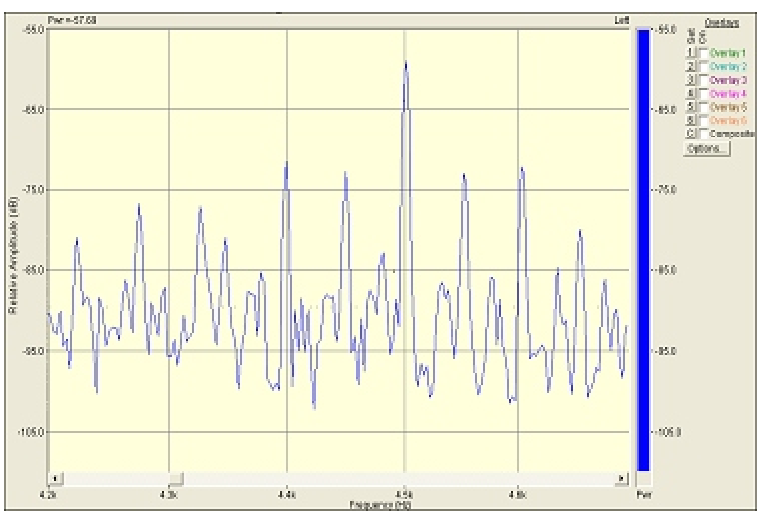

Fig. 5: A spectrum obtained when transmitter and receiver were 30 cm apart in water and no object in their path

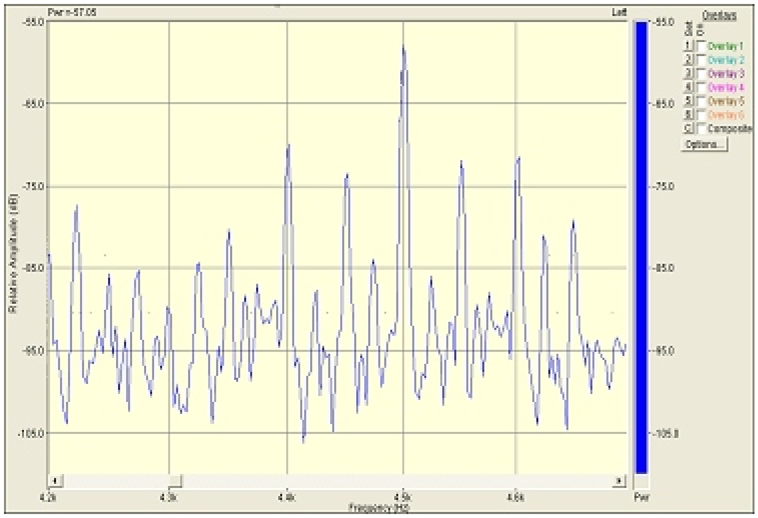

Fig. 6: Spectrum obtain when transmitter and receiver were 60 cm apart in water and no object in their path

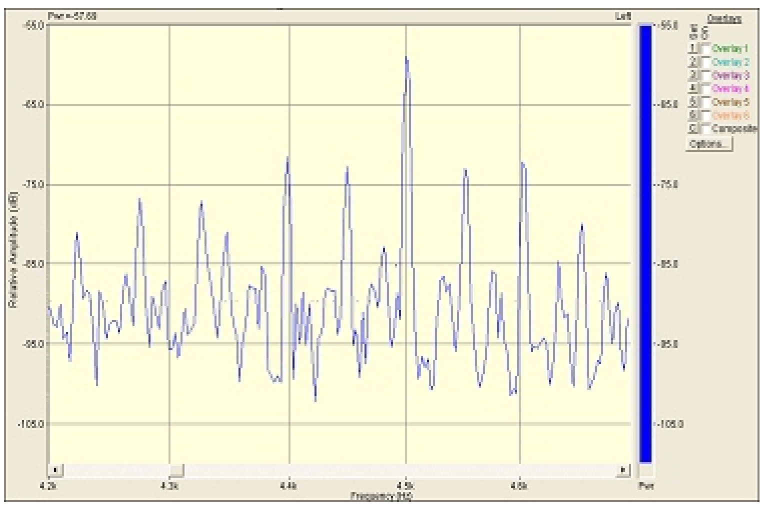

Fig. 7: Spectrum obtained when transmitter and receiver were 30 cm apart in water when plywood was in the path

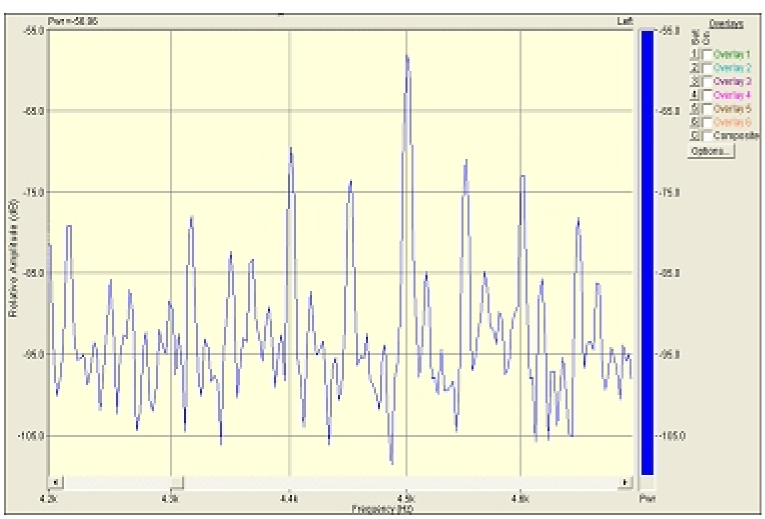

Fig. 8: Spectrum obtained when transmitter and receiver were 60 cm apart in water and plywood in the path

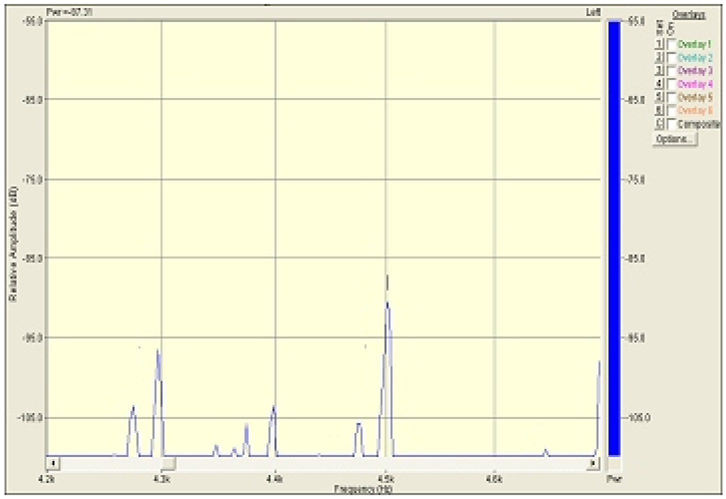

Fig. 9: Spectrum obtained when transmitter and receiver were 60 cm apart in air and plywood in between them

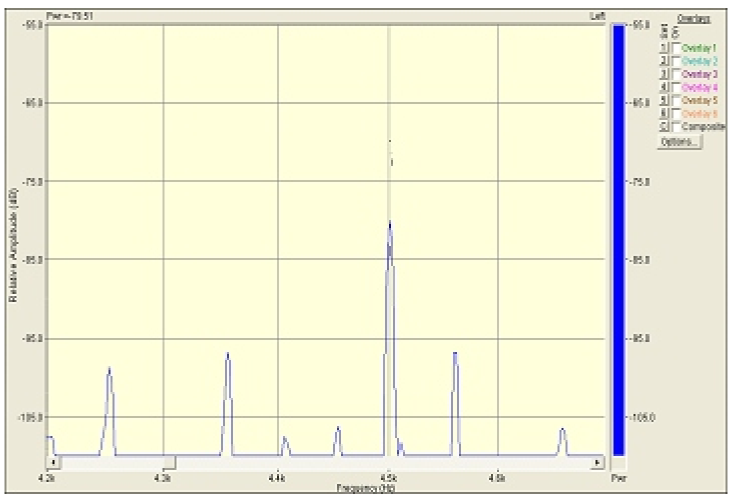

Fig. 10: Spectrum obtained when transmitter and receiver were 30 cm apart in air and plywood in between them

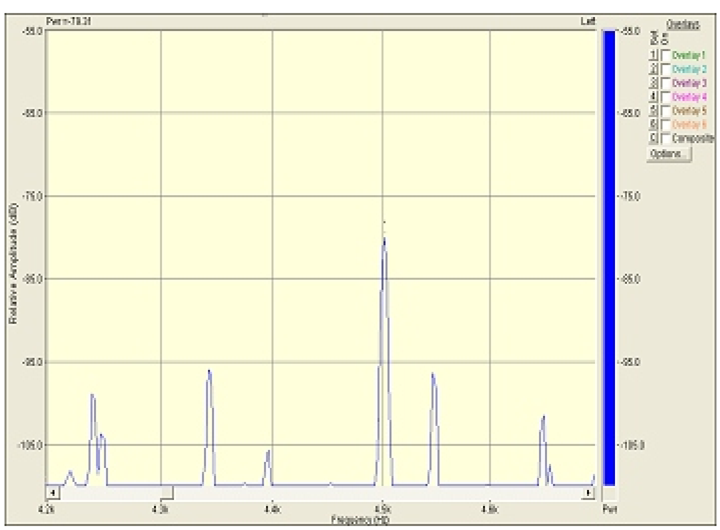

Fig. 11: Spectrum obtained when transmitter and receiver were 30 cm apart in air with asbestos in between them

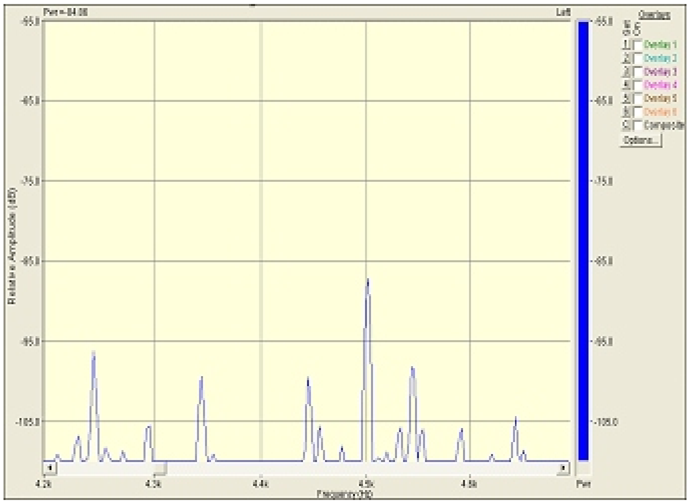

Fig. 12: Spectrum obtained when transmitter and receiver were 60 cm apart in air with asbestos in between them

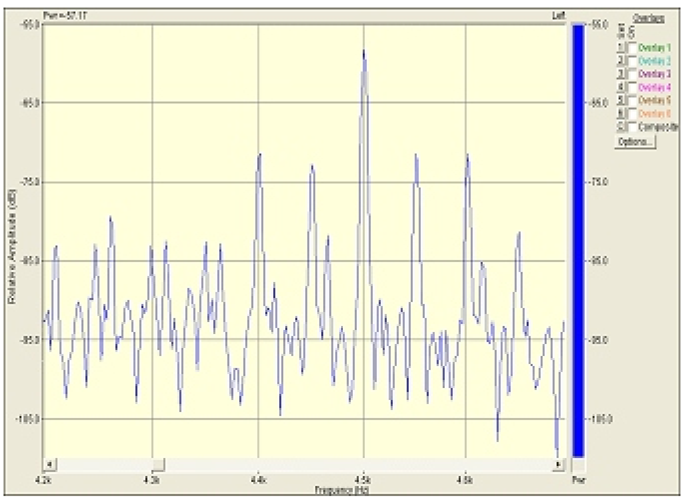

Fig. 13: Spectrum obtained when transmitter and receiver were 30 cm apart in water with asbestos in between them

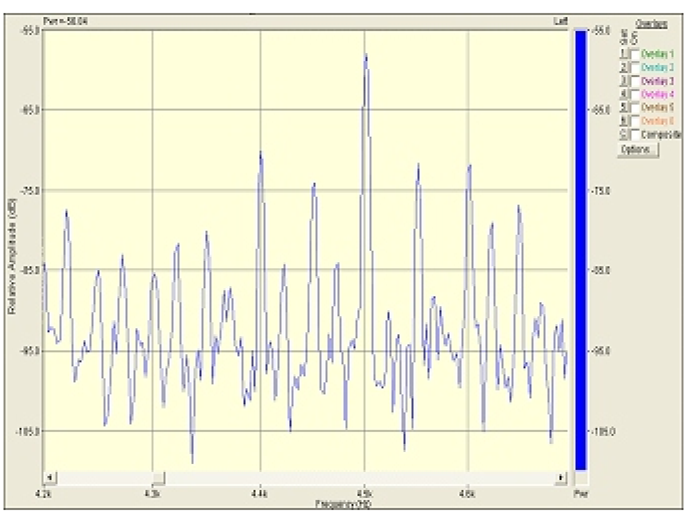

Fig. 14: Spectrum obtained when transmitter and receiver were 60 cm apart in water with asbestos in between them

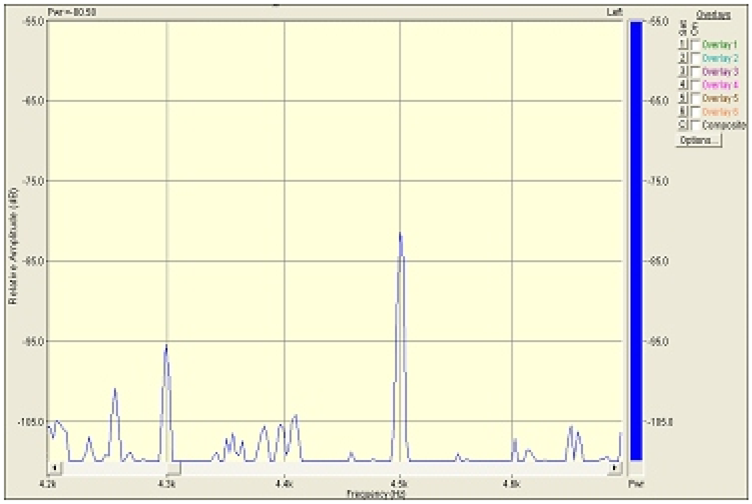

Fig. 15: Spectrum obtained when transmitter and receiver were 30 cm apart in air with PVC plastic in between them

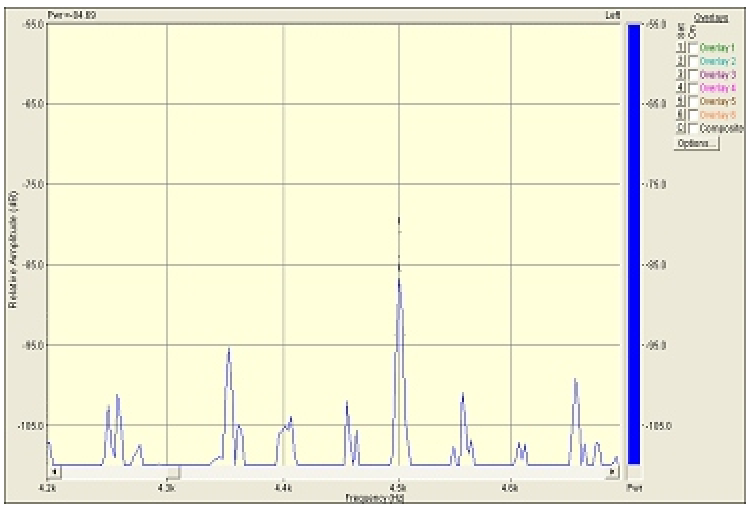

Fig. 16: Spectrum obtained when transmitter and receiver were 60 cm apart in air with PVC plastic in between them

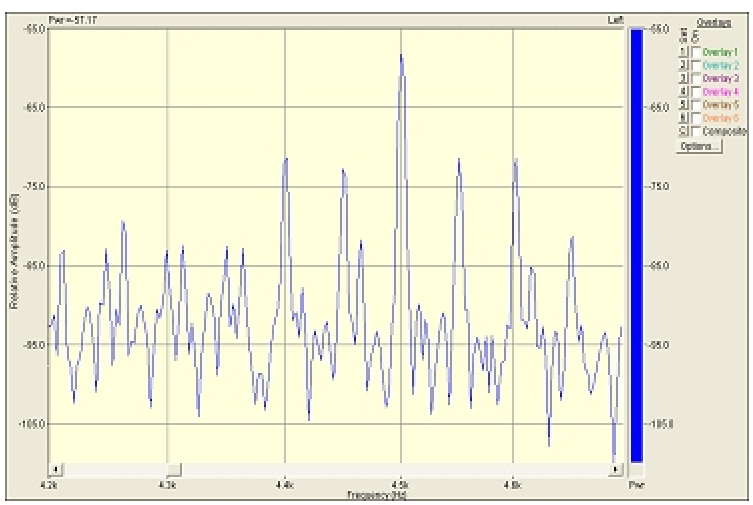

Fig. 17: Spectrum obtained when transmitter and receiver were 30 cm apart in water with PVC plastic in between them

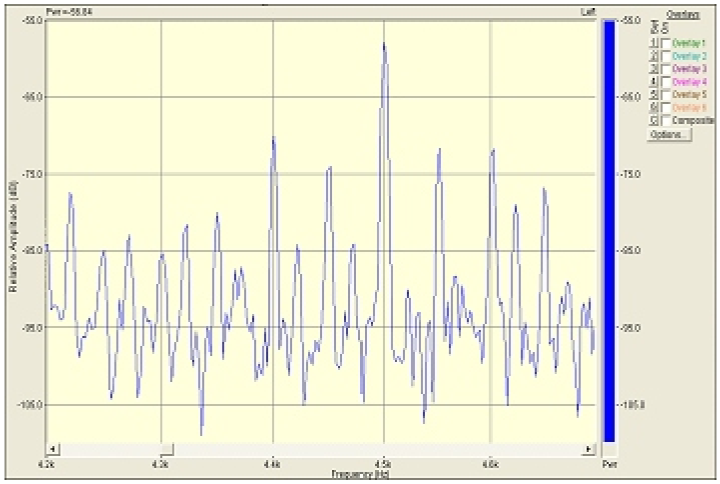

Fig. 18: Spectrum obtained when transmitter and receiver were 60 cm apart in water with PVC plastic in between them

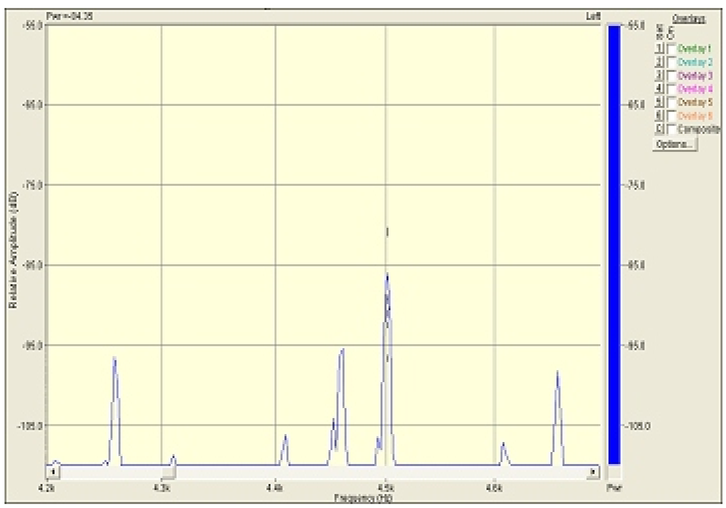

Fig. 19: Spectrum obtained when transmitter and receiver were 30 cm apart in air with iron sheet in between them

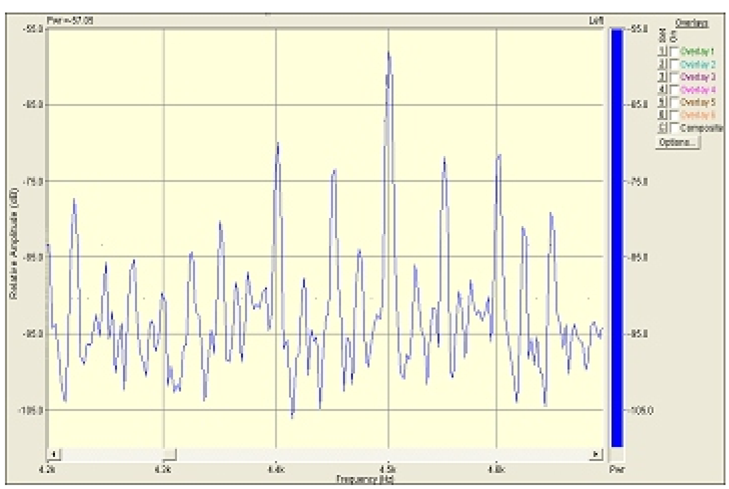

Fig. 20: Spectrum obtained when transmitter and receiver were 30 cm apart in water with iron sheet in between them

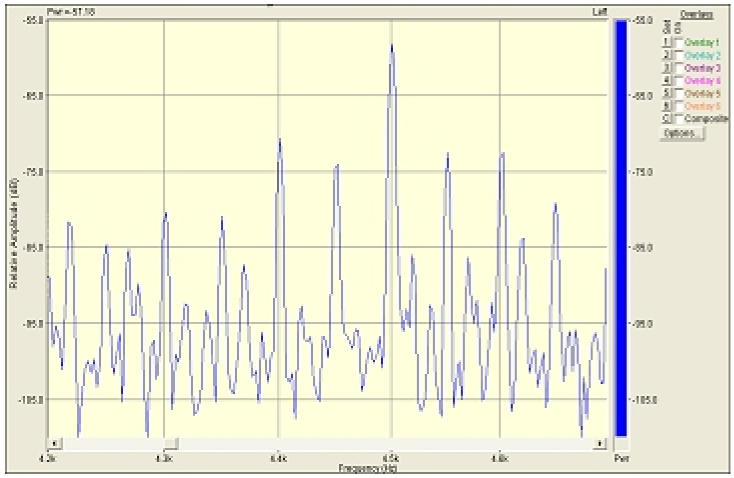

Fig. 21: Spectrum obtained when transmitter and receiver were 60 cm apart in water with iron sheet in between them

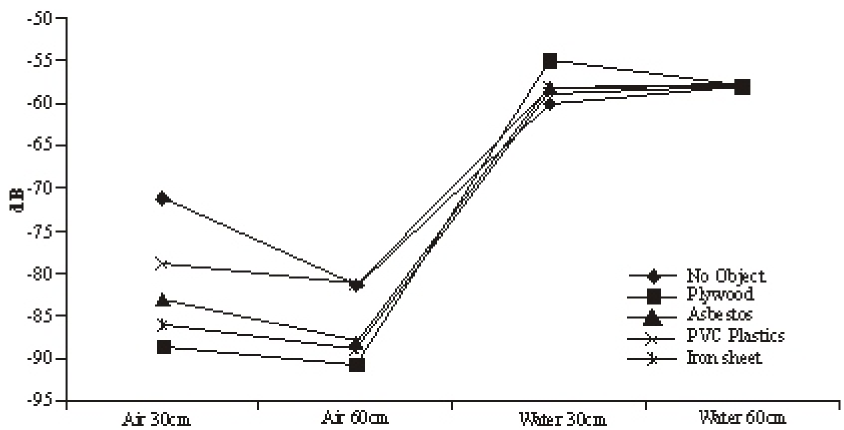

Fig. 22: Trend of signal interaction with various materials inside water and open air Room temperature is 28ºC

It can be noted also that the peak drops with distance in the air but increases with distance in the water except for the plywood. The plywood also had the least values in the air and highest value in the water for both 30 and 60 cm spacing (with the exception of the iron sheet at 60 cm transducer spacing). This brings about the question about what could be responsible for this behavior. A robot that will use such a method for navigation then must incorporate a subsystem to identify uniquely the materials in its environ perhaps based on some mathematic algorithm or on board table other wise there would be some sort of confusion. Fig. 22 gives a further pictorial view for emphasis. The plywood is expected to absorb more sonar energy and is properly shown in Table 3 for both transmitter and receiver spacing.

CONCLUSION AND RECOMMENDATION

The wristwatch piezocrystal based buzzer has the potential of being used for cheap under water navigation. At audible frequency range much investigation is still required, there is need to conduct very exhaustive experiments on the behavior of wider range of objects at the selected frequency of 4.5 kHz and perhaps other frequency.

Seeing that there is no linear relationship in material and sound absorption or attenuation even with various thicknesses, a more exhaustive test at same frequency will have to be performed. It is also good to eliminate the limitation imposed by the computer sound card (0 Hz to 20 kHz) and test the behaviour at much higher frequency - even if not the optimum. This will require a rigorous search for the highest peak or resonance if the same wrists watch piezocrystal buzzer will still be used. Amplification and signal conditioning will be a must this time unlike the experiment described above.

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