PRELIMINARY INVESTIGATION ON THE POTENTIAL OF USING LOW POWER ULTRASOUND TO INDUCE LOW FREQUENCY VIBRATIONS ON AN IMMERSED OBJECT

Spyros Kouzoupis [a], Panagiotis Papadakis [b], George Piperakis [b]

[a] Department of Music Technology and Acoustics, (TEI) Technological Educational Institute of Crete, Greece.
[b] Institute of Applied and Computational Mathematics (IACM), Foundation of Research and Technology - Hellas (FORTH).

Spyros Kouzoupis, Department of Music Technology and Acoustics, (TEI) Technological Educational Institute of Crete, Rethymnon Branch, Daskalaki 1, Perivolia, 74100 Crete, Greece. Fax: 2831021912, email: skouzo@staff.teicrete.gr

Abstract: *In this paper, an investigation is undertaken as to whether low power ultrasonic projectors in water can induce vibration on a soft object immersed in water. Experiments were conducted in a water tank using one transducer emitting an amplitude modulated (AM) pressure wave or two converging transducers each one emitting a sinusoidal wave in the 500 kHz range, while their frequencies differed by 500 to 2000 Hz. Short pulses with a rise time around 7 ns were also emitted. The objective of these experiments was to check whether ultrasound can be used to induce vibrations of fish swimbladder in the range of its resonant frequency (500-2000 Hz). In some experiments focal transducers at 5 MHz were also used. In all cases the beams were aiming at a light surface, made of plastic or nylon, where an accelerometer was mounted for picking up vibrations in the frequency range mentioned above. Results for all different setups, using directional and focal transducers are presented and discussed. Prospects for applying the method in order to cause a sound response from fish or simply study their responsive behavior, is also considered.*

Keywords: *Tank experiments, Bioacoustics, Radiation pressure.*

1. INTRODUCTION

The initiative for undertaking the present investigation was given by the need to create sounds in the low frequency range inside small tanks for the purpose of conducting experiments with soniferous fish. In these experiments sound sources need to be placed in the tank in order to conduct conditioning as well as behavioural experiments with small fish. The fish species under investigation are active in the frequency range of 300-1400 Hz. Underwater sound sources in this frequency range are bulky making the use of such sources inside the former tanks, impractical. As an alternative, ultrasonic underwater projectors, because of their small size, might be used in order to create audio sounds. This is possible but still, the space limitations confine the beams' propagation distance needed for the related phenomena to be established. Another possibility is to try to induce audio frequency vibrations through ultrasound on another object or surface (i.e. tank wall, or another floating or immersed object), which in turn will act as a secondary sound source. This technique can also be used to kind of poke the fish (through dynamic radiation pressure), by aiming the beam(s) at the fish lateral line in order to make it respond and hopefully produce sound or exhibit some other behaviour worth studying. This principle has been successfully used in the past in order to measure the vibrational response of fish swimbladders, [4].

Another, seemingly unrelated, application will be discussed by the end of this paper. We will report on a simple method of detecting whether an individual fish belonging to a species known to have a swimbladder, actually carries a swimbladder. It does happen that some fish do not develop a swimbladder as they should do. The method is based on the reflection characteristics of a short ultrasonic sound pulse and is described at the end of this paper.

2. SERIES OF EXPERIMENTS

Three groups of experiments (A, B and C) are reported:

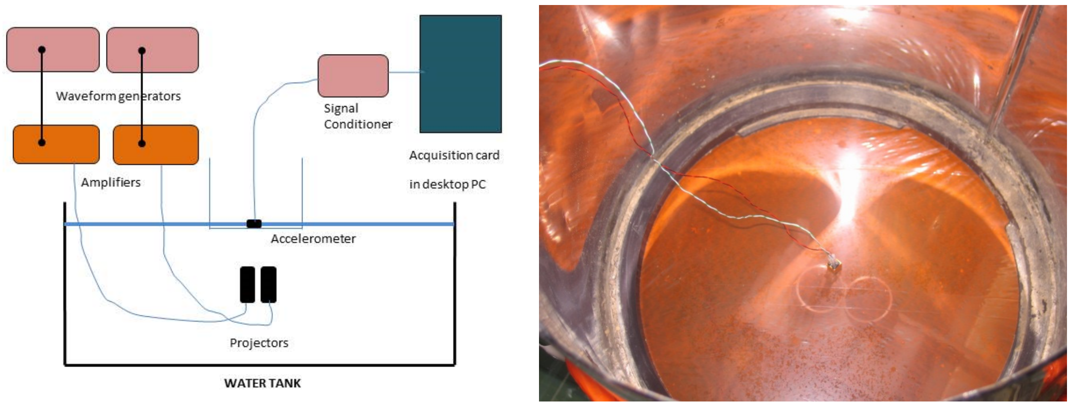

Fig. 1: Experimental setting and a photo showing the accelerometer and the projectors underneath.

A) Equipment used: Two ultrasonic immersion projector beam transducers were used in this experiment (V389, Panametrics). These transducers are piezoelectric elements with central frequencies around 500 kHz and bandwidths of 200 kHz. The beamwidths of the narrow beams depend on the transducer head sizes. The manufacturer of the transducers does not provide calibration charts and documents for these instruments. Their head diameters were 1.75" inches. The two ultrasonic immersion projector beam transducers were directed towards the water-air interface, in an angle of ~10^o between them, in such distance so that the two beams interact exactly at the thin and light plastic surface which formed the bottom of a floating round can (with diameter of 35 cm), where an accelerometer (ENDEVCO 35A, triaxial piezoelectric accelerometer) was mounted at the inside (Fig.1). One transducer was sending CW wave at 500 KHz while the frequency of the second transducer was changing on every trial, spanning a range from: 500.25 to 515 kHz (actual values tried, were: 500.25, 500.5, 501, 502.5, 505, 507.5, 510, 515 kHz). The accelerometer signal was passed through a signal conditioner (PCB 482A16) and was sampled and recorded via a PCI data acquisition card (SPECTRUM High speed 50 MHz, DAC). The spectra of the accelerometer signals for the cases where the projectors' frequencies differed by 1 and 2.5 kHz, are shown in Fig. 2. It is evident that the dynamic component of the radiation pressure is detected by the accelerometer. Other similar experiments were also conducted using a small thin plastic cap floating on the water surface or a floating plastic ball with an accelerometer (PCB 352810 ICP), mounted at the bottom of the cap and at the top of the ball, respectively. A Panametrics custom made focal transducer with 5 MHz working frequency was placed underwater facing the cap (or ball) bottom at a distance equal to its focal distance (2.54 cm) and was driven via an arbitrary waveform generator (TTi TGA1241), sending an amplitude modulated signal with 5 MHz carrier frequency, 1 kHz modulating frequency and amplitude of 6 V (p-p). The accelerometer signal was amplified through the signal conditioner mentioned above. We obtained similar results with the ones shown in Fig. 2, where there was also a prominent 1 kHz component.

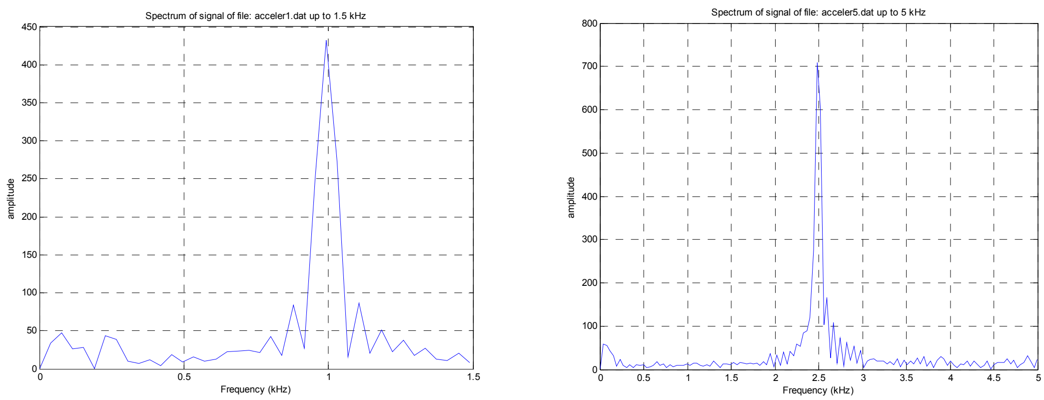

Fig. 2: Accelerometer signal spectra. Frequencies differed by 1 and 2.5 kHz, respectively.

B) At this experiment a thin stainless steel bar (of length 45 cm, width of 3 cm and thickness of 0.6 mm), was suspended with almost half of it submerged in water and having an accelerometer (PCB 352810 ICP), mounted close to the bar's upper end. The water-air interface was at 34.5 cm from the bar submerged end and the focal transducer was placed horizontally at a distance of 2.54 cm (focal distance), facing the bar and at a level of 12 cm from the water surface. The focal transducer was driven with an amplitude modulated signal having 5 MHz carrier frequency, 1 kHz modulating frequency, while the accelerometer signal was boosted 100 times through the signal conditioner and recorded using 44 kHz sampling frequency. The 1 kHz component is also evident here, as seen in

Fig. 3. Besides that, driving the focal transducer with a tone burst similar to that of Fig. 4, caused the rise up of multiple components in the accelerometer signal spectra due to the excitation of the bar's eigenfrequencies.

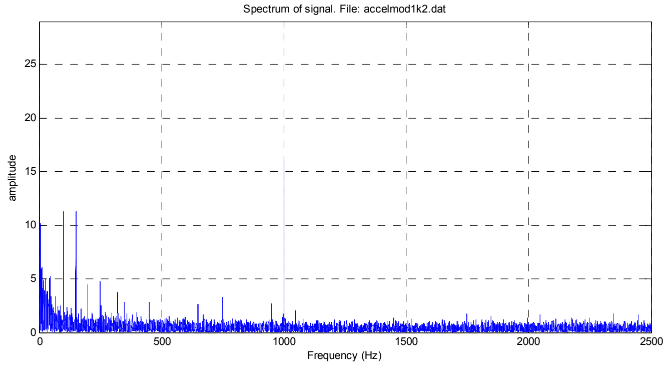

Fig. 3: Accelerometer signal spectrum of thin metal bar excited by a focal transducer.

C) At this experiment we investigated the possibility of using sound in order to detect whether an individual fish carries a swimbladder. At this stage, instead of using actual fish, we tested the ultrasound based method by looking at backscattering signatures from soft and hard round targets. A directional transducer with a small head (V318, Panametrics), having central frequency around 500 kHz and bandwidth of 200 kHz, was used both to send and receive a short pulse. A 100 V tone burst (its shape shown in Fig. 4), was sent from a pulser-device (Panametrics 5058PR) and its reflection from a hard surface or a submerged air balloon, was recorded to a PC through a high speed Data Acquisition Card (DAC). The width of the pulse sent was about 25 ns (although at the pulse shape Fig. 4, the number of samples is shown). The onset time of the pulse was less than 10 ns (~7 ns). Special developed software undertook the whole process (i.e. triggering the send and receive modes and record the waveform). Sampling frequency was 40 MHz, the receiving signal was low pass filtered (with cutoff frequency set at 1 MHz), and an averaging of 4 waveforms was performed. Results for the two cases are shown in Fig. 5, below. Both waveforms, reflected from a hard and soft surface, respectively, look quite different than the emitted pulse due to the transducer response. We notice that in each case although the received pulse has several local extremes we could always single out one extreme that its absolute value was higher than the rest. When the reflection comes from a hard surface the sign of the strongest peak is negative and vice versa.

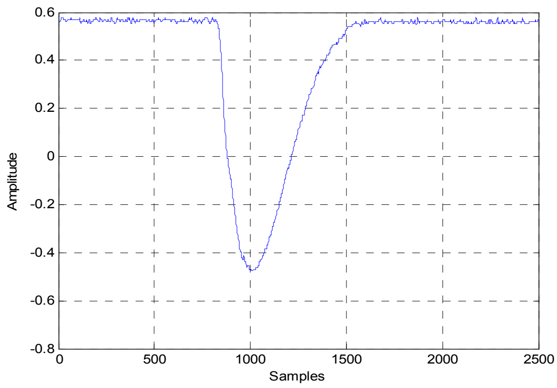

Fig. 4: Tone burst shape emitted from the directional transducer

This fact was confirmed in many trials and based on this pattern, we added few lines of code in the recording software to automatically classify whether a target is hard or soft. We claim that this method is simpler than other similar methods [5], and can be used to detect whether an individual fish actually carries a swimbladder. We plan to test this method using in real fish.

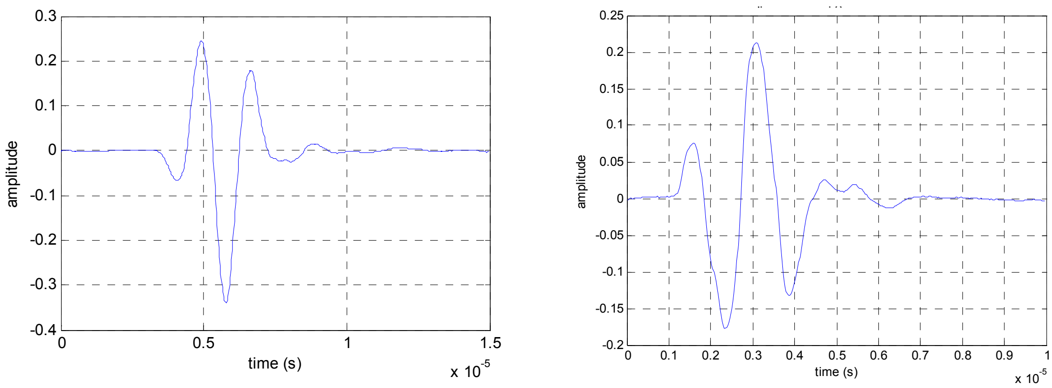

Fig. 5: Reflected tone burst waveform types from a hard (left) and soft (right) target.

3. DISCUSSION - CONCLUDING REMARKS

Three series of experiments were presented in order to check whether it is possible to induce vibrations on a submerged object and potentially use it to 'agitate' fish in laboratory tanks with the purpose of provoking and studying their response (i.e. the production of sound that some species are capable of [2]), which has otherwise been difficult to detect and record. This can be accomplished through the creation of a time dependent (dynamic) component in ultrasound radiation force [1], by using either two interacting continuous-wave ultrasound beams, with slightly different frequencies, or amplitude modulated ultrasound beams. Pulsed ultrasound beams can also be used. Even though we did not use high intensity beams, our results show that this method could have the desirable results when applied to real fish. At this time, an estimate of the exerted radiation force cannot be deduced, because the manufacturer, for the transducers used, does not provide sensitivity data and the particle velocity at the source position is not known. The authors have already been making efforts to calibrate all available transducer equipment in their lab, [3].

A simple technique for detecting fish with or without a swimbladder, by analyzing the backscattering signature of an ultrasound burst tone, was also proven reliable, but it remains to be tested on real fish targets.

ACKNOWLEDGEMENTS

This research has been co-financed by the European Union (European Social Fund – ESF) and Greek national funds through the Operational Program "Education and Lifelong Learning" of the National Strategic Reference Framework (NSRF) - Research Funding

Program: ARCHIMEDES III. Investing in knowledge society through the European Social Fund.

REFERENCES

[1] **Silva Glauber, Chen Shigao, Greenleaf James and Fatemi Mostafa**, "Dynamic ultrasound radiation force in fluids", *Physical Review E* 71(5), 056617, (2005).
[2] **S. Kouzoupis, P. Papadakis, V. Boura, I. Xezonakis and M. Kentouri**, "Preliminary investigation on sound production by two fish species: Sparus Aurata and Dicentrarchus Labrax". *Proceedings of the Institute of Acoustics*, vol. 29. Pt.3, (2007), pp. 225-232. *Fourth International Conference on Bioacoustics*, Holywell Park, Loughborough University, UK.
[3] **P. Papadakis, G. Piperakis and S. Kouzoupis**, "Calibration of ultrasound transducer heads using short preprocessed ultrasonic pulses", (in this Volume), *UA 2014, Underwater Acoustics Conference*, Rhodes, Greece, 22-27 June 2014.
[4] **Lewis Thomas and Rogers Peter**, "The vibrational response of single-chambered fish swimbladders to low-frequency sound", *ICES Journal of Marine Science*, 53, pp. 285-287, 1996.
[5] **Tucker D. G. and Barnickle N. J.**, "Distinguishing automatically the echoes from acoustically 'hard' and 'soft' objects", *Journal of Sound and Vibration*, 9(3), pp. 393-397, (1969).