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Experiments in Acoustics for the Undergraduate Physics Laboratory

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Abstract: ***Although a variety of experiments in mechanics, optics, heat and electricity form a part of the undergraduate physics curriculum, the number of experiments in sound, in most undergraduate physics and engineering laboratories, is very limited. A dearth of experiments in sound leads to an incomplete understanding of concepts in acoustics that is revealed as the student advances through a university degree or diploma program. A set of four new experiments in sound for the undergraduate laboratory that should assist understanding of concepts central to a typical acoustics theory course, is offered. These experiments are appropriate for a course in acoustics that is offered as a part of applied physics or engineering***

Keywords: physics curriculum; undergraduate physics laboratory; experiments in sound; course in acoustics

1. Introduction

Most physics taught at the undergraduate level is reinforced by experiments performed concurrently in the laboratory. Although a large number of experiments in the areas of mechanics, optics, heat and electricity are readily available, the fact that the number of laboratory experiments in sound, in most undergraduate laboratories is limited is well known. A dearth of experiments leads to a deficient understanding of concepts in acoustics that manifests itself as the student progresses to higher levels within the undergraduate curriculum. These shortcomings remain obscure until the student is found grappling with simple ideas relating to transducers, resonators, filters, etc., not to mention his inability to apply basic acoustic criteria for selection of appropriate devices like microphones and loudspeakers, for common acoustic applications.

It is evident that components like resonators and filters in a typical acoustics course would be better understood when experiments involving mufflers are performed concurrently. Furthermore, fundamentals in acoustics discussed in textbooks viz. vibration of strings and membranes, the transmission phenomenon, reverberation time, etc. would be absorbed better if the student performs experiments on interference of sound simultaneously.

This article offers a set of four such experiments in sound which when incorporated into the undergraduate physics laboratory should enhance understanding of concepts that are central to a typical acoustics theory course. These experiments are also appropriate for a course in acoustics that is offered under applied physics or engineering [1], [2].

2. The Experiments and Objectives

1. Expansion chamber muffler: investigation of muffler response as a filter in the low frequency approximation by determining insertion loss; appreciation of design parameters effecting insertion loss *(Appendix I)*
2. Polar characteristics of microphone: determine polar response by measuring open circuit voltage generated at varying orientations; plotting the polar response pattern; classification of microphones on the basis of polar response *(Appendix II)*
3. Frequency response of loudspeaker: determine frequency response by measuring sound pressure level (SPL) for a true characteristic; plotting semi-log graph (SPL versus log frequency); categorize a given speaker as a woofer, midrange or tweeter *(Appendix III)*
4. Interference of sound using PC speakers: studying the interference pattern; comparing experimental observations with theoretical calculations leading to verification of the superposition principle *(Appendix IV)*

3. The Apparatus

There is no need to acquire any apparatus afresh. Experiments number 2 and 3 can be performed using a typical public-address system (with an independent microphone, loudspeaker and amplifier) that commonly exists in most institutions. Experiment number 4 can be performed using PC speakers and a function generator readily available in most laboratories. Nevertheless, for experiment number 1, a visit to the workshop would be necessary: pipes made of fiber-glass or plastic, generally employed for irrigation or drainage purpose (along with caps that go with them) can be used to build a muffler. One such simple design is cited in Fig. 1.

4. Organization

Each experiment could be set up as a lab corresponding to a section in an acoustics theory course. The experiments together could also form a separate lab course offered under applied physics or engineering. Alternatively, the experiments could be integrated into a course offered at senior level of a degree or diploma curriculum, as in the case of BS (Physics) at the University of Pune, India [3], [4].

5. Conclusion

Experiments in sound that are easy to set up, yet greatly aid understanding of concepts and applications discussed in most acoustics curricula, are suggested. Experiments recommended here could be significant additions to existing lists of experiments in sound in undergraduate laboratories and thus offer a larger pool of experiments to choose from. Adaptations of experiments 1 and 2 have already been incorporated into the lab course corresponding to the acoustics theory course viz. ‘Acoustics and Entertainment Electronics’ offered at the senior level of BSc (Physics) at the University of Pune, India [3]. Likewise experiment 3 has also been recently incorporated (2013) into the revised MSc II (Physics) Acoustics II Lab Course [4]. The experiments have been performed and well received by undergraduate physics students during summer schools at the National Academy of Sciences India and the University of Pune. These have also been performed as open-ended experiments by faculty attending refresher courses in order to motivate them to construct augments to the existing laboratory setups in their institutions.

6. Future scope

It is proposed that enhanced versions of experiments 2 and 3 be a part of the ‘Transducer Testing and Calibration Suite’ being developed at the Electro-Acoustics Research Laboratory: Incorporating a programmable waveform generator for excitation, a sound level meter with a PC interface for data logging and a storage oscilloscope instead of a CRO should enhance these setups to professional grade calibration systems. Furthermore, it is proposed that simplified versions of experiments 1 and 4 be employed as teaching-experiments to accompany discussions on filters and demonstration of interference of sound: Comparing electrical and mechanical analogues to an acoustic system assists its analysis and therefore a demo-version of the expansion chamber experiment would go a long way in dealing with design parameters for reactive mufflers in the classroom.

Appendix I: Expansion chamber muffler

A muffler also known as a “silencer” is a tubular acoustic device inserted in the exhaust system of an automobile engine or machine for reducing the level of noise. Mufflers are designed to reflect sound waves in such a way that they cancel themselves out. Ideally, the high-pressure part of the wave that comes from the engine lines up with the low-pressure part of the wave reflected off the chamber wall, and the two waves cancel each other. The dimensions of a muffler are such that the waves reflected help cancel-out certain frequencies of sound in the exhaust.

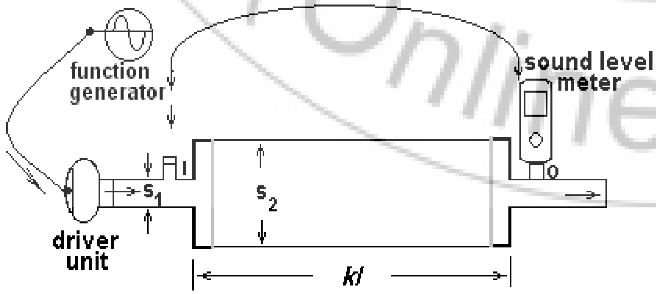

Fig.1

Mufflers are broadly divided into two categories: dissipative and reactive. A dissipative muffler relies predominantly on the presence of flow resistive material within, whereas a reactive muffler doesn’t [1]. The objective of this experiment is to determine reduction in noise (insertion loss) due to an expansion chamber type reactive muffler and understand design parameters.

Arrange apparatus and connect the circuit as shown in Fig. 1. Select a frequency of 100 Hz and a suitable signal amplitude. Record the sound pressure level (SPL) in dB at the input port (I) and the output port (O) using the sound pressure level meter. Repeat for frequencies 200, 300, 400… 1000, 2000, 3000…., 8000Hz maintaining the same amplitude. Determine the insertion loss by taking the difference of SPL values corresponding to each frequency. Plot a graph of insertion loss versus frequency. Determine frequencies at which insertion loss is maximum. Verify if the loss is minimum at $kl = n\pi$, where $k=2\pi/\lambda$ ($n = 1, 2\ 3\ldots$).

Note that noise coming from an engine is a mixture of many different frequencies. A muffler is designed to work best in the frequency range where the engine generates maximum noise.

Appendix II: Polar characteristics of microphone

The polar characteristic or pickup pattern of a microphone is the way in which it responds to sound coming in from different directions. The polar response is useful in selecting the right microphone for a specific application, particularly in a multi-microphone setting. Polar charts shown below (Fig. 2) illustrate typical response patterns for different microphones.

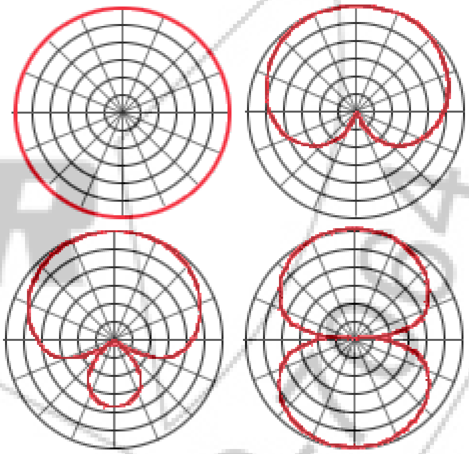

Figure 2: Omnidirectional Cardioid Super cardioid Bidirectional

Omnidirectional microphones pick up sound equally from all directions. The cardioid microphone is most sensitive to sound coming in on its primary axis. It rejects sound moderately from the sides and entirely from the rear. Another polar pattern encountered is the supercardioid. Although the supercardioid pattern is similar to the cardiod, it has an additional rear lobe, which means it also responds a little to sound incident from the rear [1], [5], [6]. A supercardiod could be used, say by a sports-commentator, where adding a limited reaction from the spectators in the stadium would add to the listener’s excitement without masking the commentator’s voice. A somewhat unusual but very useful pickup pattern is that of the bidirectional microphone. A bidirectional microphone is most sensitive to sound coming in from the front and rear, and rejects sound coming in from the sides. This microphone for example, is useful in an interview like situation where there are two speakers facing each other.

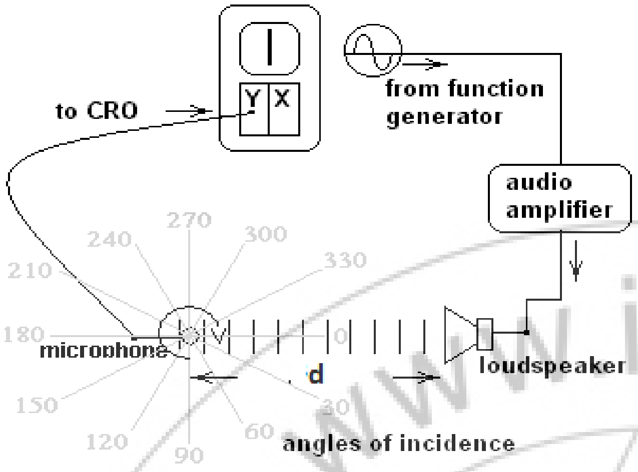

Fig. 3 Experimental setup

The objective of this experiment is to obtain and compare polar response of a given set of microphones. The setup involves a function generator, an audio amplifier, a loudspeaker and a CRO (Fig. 3). A fixed frequency (1000Hz) and constant power is used to drive the loudspeaker. The amplitude of the signal generated in response by the microphone is recorded at different angles of incident sound. Plotting these amplitudes on the polar graph gives the polar characteristic of the microphone.

Appendix III: Frequency response of loudspeaker

The sound pressure level (SPL) at a fixed distance from a loudspeaker varies with frequency. This variation in SPL (dB) with frequency for a constant input gives frequency response of the loudspeaker. It is this frequency response which determines whether a loudspeaker could be used for sound-reproduction in a given frequency range. Note that a single loudspeaker does not respond to the entire audible range and therefore we often see a combination of loudspeakers (woofer, tweeter and squawker) being used for a faithful and complete reproduction of sound (fidelity). Each of these loudspeaker types has its own characteristic frequency response [1], [6], [7].

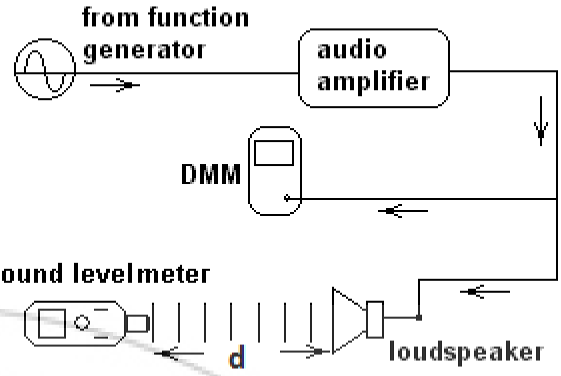

Fig. 4 Experimental setup

In this experiment we observe the variation in SPL with frequency at a fixed distance from a direct radiator loudspeaker. The setup consists of a sound level meter, a digital multimeter (DMM), a function generator and an audio amplifier that drives the loudspeaker (Fig. 4). The sound level meter is used to measure SPL at a fixed distance from the loudspeaker at frequencies 100, 200, 300, 400… 1000, 1200, 1400… 2000, 2500, 3000…, 8000Hz. The input voltage is maintained at a constant value throughout the experiment. A plot of SPL versus $\log_{10}f$ gives the frequency response of the loudspeaker.

Appendix IV: Interference of sound

The experiment on interference of sound resembles the Young's double-slit experiment where light passes through a pair of closely spaced narrow slits and produces a pattern of alternating bright and dark fringes. The angle theta for the n^{th} order bright fringe (maximum) is given by $\sin\theta = n\lambda/d$, where d is the spacing between the slits (n = 0,1,2,3….). Similarly the angle for the dark fringe (minimum) is given by $\sin\theta = (n+1/2)\lambda/d$.

S_1 and S_2 are two loudspeakers emitting sound waves separated by a distance d and driven by the same function generator so that they are in phase and emit waves of the same frequency. A microphone is moved along a metre-scale placed parallel to the line joining the two sources at a distance D to detect the intensity of sound (Fig. 5).

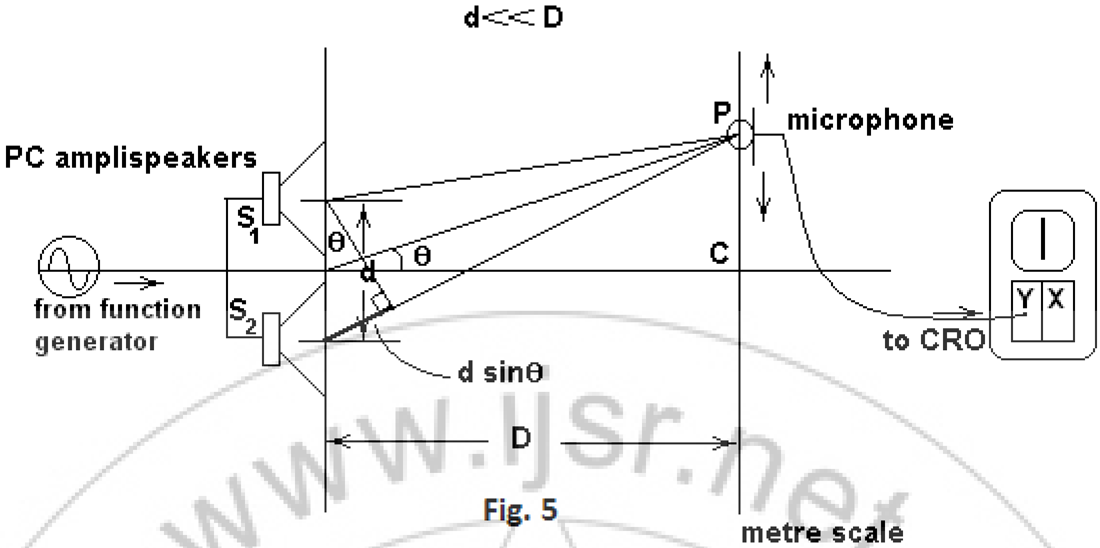

Fig. 5

The path difference at P between the waves generated by S_1 and S_2 is $d\sin\theta$. When the path difference is an even multiple of half wavelength, waves arriving at P (from S_1 and S_2) will be in phase and interfere constructively i.e. the intensity of sound detected by the microphone will be maximum. However, when the path difference is an odd multiple of half wavelength the waves will be out of phase and interfere destructively i.e. the intensity of sound detected will be minimum. The position of the maxima and minima on the meter scale will be different for different values of frequency [8].

The speakers are placed 13-20cm apart. The sine wave frequency is set between 4-15 kHz. D is set to 30 cm. The microphone is moved along the metre-scale and points of maximum intensity are located. One of the locations of constructive interference will be point C equidistant from each speaker. The distance between C and the first maximum P is measured over the meter scale. We then determine θ experimentally using $\sin\theta = CP/\sqrt{D^2+CP^2}$ and also using $\sin\theta = n\lambda/d = nc/fd$ (n = 1) theoretically. The procedure is repeated to *determine* find θ for different values of frequency, for a fixed separation d, and distance D. An agreement between the two sets of values is a verification of the superposition principle.

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Author Profile

Dr. Farhat Surve obtained his Master's degree in Physics jointly from TIFR and the University of Pune in 1987. He obtained his PhD (Physics) from the University of Pune in 2001. Dr. Farhat Surve is a Fulbright Fellow and has 25 years of teaching experience including teaching at State University of New York, Buffalo, and the Pennsylvania State University. He is presently Associate Professor at the Nowrosjee Wadia College, University of Pune. He is the recipient of the American Physical Society Kilambi Ramavataram Fellowship wherein he worked on teaching-experiments at the Kansas State University. His research interests include rectification algorithms for flawed room acoustics, overtone dynamics, impedance characterization and building acoustics. His work in physics education involves augmentation of open ended extensions to the undergraduate laboratory including structured pre and post-lab tutorials. Dr. Farhat Surve is the recipient of the Pune University's 'Innovation in Teaching Award', 2002, the Indian Physics Association's Pune Chapter's 'Bhaskar Raye Best Teacher Award', 2012, and CDAC's Best Paper Award at the ICPCCS, 2012 amongst others.